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THESIS

FREQUENCY RESPONSE STUDY OF NONLINEAR NETWORKS
BY PARAMETER PLANE TECHNIQUES

by

Fernando Manuel Palma Ruivo

September 1968

THESIS
R856

[redacted]

FREQUENCY RESPONSE STUDY OF NONLINEAR NETWORKS BY PARAMETER PLANE TECHNIQUES

by

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Lieutenant, Portuguese Navy
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[redacted]

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

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September 1968

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Thesis
R856
C.2

ABSTRACT

The use of parameter plane curves of output voltage magnitude versus one of the parameters as a means of obtaining the frequency response of nonlinear networks was investigated for networks containing one nonlinear element, which was a function of the magnitude of the voltage across it. The results obtained were checked by digital simulation and it may be concluded that the method is reliable. The method was also presented as a way of obtaining information for the reshaping of network frequency response by introduction of the proper nonlinear elements.

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1. Introduction to Parameter Plane Techniques

Parameter plane work was first developed to investigate the effects of the variation of two elements (parameters) upon the location of the roots of the characteristic equation of control systems.

Because of the nature of the characteristic equation, this work was later extended to the analysis and design of networks with linear elements, especially because of the possibility of controlling and modifying the characteristics of the network by the variation of two of its elements.

The referred parameters are considered to be varied slowly and to be time invariant, as far as the development of parameter plane techniques are concerned; but the present work extends one of the aspects of this utilization, by using them in the study of the frequency response of networks with nonlinear elements, with time variations of their own.

Basically the parameter plane method can be applied to the analysis of any polynomial with variable coefficients.

Consider the equation

$$f(s) = \sum_{k=0}^{m} a_k s^k = 0 \tag{1-1}$$

where a_k are real coefficients and s is the complex frequency variable ($s = \sigma + j\omega$).

Considering the Chebyshev functions of the first and second kind,

$$T_k(-\zeta) = (-1)^k T_k(\zeta) \tag{1-2}$$

and

$$U_k(-\zeta) = (-1)^{k+1} U_k(\zeta) \tag{1-3}$$

and because $s = -\zeta\omega_n + j\omega_n\sqrt{1-\zeta^2}$, it follows that:

$$s^k = \omega_n^k \left(T_k(-\zeta) + j\sqrt{1-\zeta^2}\; U_k(-\zeta) \right) \tag{1-4}$$

T_k and U_k obey to the recursion relationships given by the tables of the Chebyshev functions

Table I-1

$$T_{k+1}(\xi) = 2\xi T_k(\xi) - T_{k-1}(\xi)$$

$$U_{k+1}(\xi) = 2\xi U_k(\xi) - U_{k-1}(\xi)$$

$$T_0(\xi) = 1 \qquad T_1(\xi) = \xi$$

$$U_0(\xi) = 0 \qquad U_1(\xi) = 1$$

Equation 1-4 results from the fact that:

$$s = -\omega_n \xi + j\omega_n \sqrt{1-\xi^2}$$

where ω_n is the undamped natural frequency and ξ is the damping coefficient;

also $s = \omega_n(\cos\theta + j\sin\theta) = \omega_n e^{j\theta}$, if $\theta = \cos^{-1}(-\xi)$

Then $s^k = \omega_n^k e^{jk\theta} = \omega_n^k(\cos k\theta + j\sin k\theta)$; and

defining: $T_k(-\xi) = \cos k\theta = \cos(k\cos^{-1}(-\xi))$

$$U_k(-\xi) = \frac{\sin k\theta}{\sin\theta} = \frac{\sin(k\cos^{-1}(-\xi))}{\sin(\cos^{-1}(-\xi))}$$

the result is:

$$s^k = \omega_m^k \left[T_k(-\zeta) + j\sqrt{1-\zeta^2}\; U_k(-\zeta) \right] \tag{1-4}$$

Using the recursion relationships for the T and U functions:

$$s^k = \omega_n^k \left[(-1)^k\, T_k(\zeta) + j\sqrt{1-\zeta^2}\,(-1)^{k+1}\, U_k(\zeta) \right] \tag{1-5}$$

Using these expressions for s in one original equation for the polynomial in s, there results a complex expression, for which the real and imaginary parts are equated to zero independently, resulting in two equations

$$\sum_{k=0}^{m} a_k\, \omega_n^k\, (-1)^k\, T_k(\zeta) = 0 \tag{1-6}$$

$$\sum_{k=0}^{m} a_k\, \omega_n^k\, (-1)^{k+1}\, U_k(\zeta) = 0 \tag{1-7}$$

Using Table I-1, one obtains the relationship

$$T_k(\zeta) = \zeta\, U_k(\zeta) - U_{k-1}(\zeta) \tag{1-8}$$

and finally for (1-6) and (1-7)

$$\sum_{k=0}^{m} (-1)^k\, a_k\, \omega^k\, U_{k-1}(\zeta) = 0 \tag{1-9}$$

$$\sum_{k=0}^{n} (-1)^k\, a_k\, \omega^k\, U_k(\zeta) = 0 \tag{1-10}$$

These expressions lead to the final expression of α and β in terms of ζ and ω_n for the cases when the coefficients a_K are of the form

$a_K = b_K\alpha + c_K\beta + d_K$, where α and β show up only in linear combination.

For a reasonably general situation, the coefficients a_K are considered to be functions of the two variable parameters, with the form

$$a_K = b_K\alpha + c_K\beta + d_K\alpha\beta + f_K$$

when b_K, c_K, d_K, f_K are constant and real coefficients and α and β the two real variable parameters.

Using the previous derivations for s^K and the T_K and U_K functions, the following expression is obtained:

$$F(s) = \sum_{K=0}^{n} a_K \omega_n^K T_K(-\zeta) \pm j\sqrt{1-\zeta^2} \sum_{K=0}^{n} a_K \omega_n^K U_K(-\zeta) \tag{1-11}$$

Manipulation of the relations in Table I-1 leads to equations 1-6 and 1-7, and by substitution of the general expression for a_K into them, there results,

$$B_1\alpha + C_1\beta + D_1\alpha\beta + F_1 = 0 \tag{1-12}$$

$$B_2\alpha + C_2\beta + D_2\alpha\beta + F_2 = 0 \tag{1-13}$$

These were obtained from the equations

$$\alpha\sum_{K=0}^{n}(-1)^K b_K\omega^K T_K(\zeta) + \beta\sum_{K=0}^{n}(-1)^K c_K\omega^K T_K(\zeta) + \tag{1-14}$$

$$+\alpha\beta\sum_{K=0}^{n}(-1)^K d_K\omega^K T_K(\zeta) + \sum_{K=0}^{n}(-1)^K f_K\omega^K T_K(\zeta) = 0$$

and

$$\alpha \sum_{k=0}^{n} (-1)^k b_k w^k U_k(\xi) + \beta \sum_{k=0}^{m} (-1)^k c_k w^k U_k(\xi) +$$

$$+ \alpha\beta \sum_{k=0}^{n} (-1)^k d_k w^k U_k(\xi) + \sum_{k=0}^{m} (-1)^k f_k w^k U_k(\xi) = 0 \qquad (1\text{-}15)$$

and by calling

$$B_1 = \sum_{k=0}^{m} (-1)^k b_k w^k T_k(\xi)$$

$$B_2 = \sum_{k=0}^{n} (-1)^k b_k w^k U_k(\xi)$$

$$C_1 = \sum_{k=0}^{n} (-1)^k c_k w^k T_k(\xi)$$

$$C_2 = \sum_{k=0}^{m} (-1)^k c_k w^k U_k(\xi)$$

$$D_1 = \sum_{k=0}^{n} (-1)^k d_k w^k T_k(\xi) \qquad (1\text{-}16)$$

$$D_2 = \sum_{k=0}^{n} (-1)^k d_k w^k U_k(\xi)$$

$$F_1 = \sum_{k=0}^{n} (-1)^k f_k w^k T_k(\xi)$$

$$F_2 = \sum_{k=0}^{m} (-1)^k f_k w^k U_k(\xi)$$

By elimination of α, an expression for β is obtained in the following fashion, from (1-12) and (1-13):

$$\alpha = \frac{F_1 + C_1\beta}{B_1 + D_1\beta} = \frac{F_2 + C_2\beta}{B_2 + D_2\beta}$$ or

$$\Delta_{CD}\,\beta^2 + (\Delta_{FD} + \Delta_{CB})\,\beta + \Delta_{FD} = 0$$

where

$$\Delta_{CD} = C_1 D_2 - D_1 C_2 \;, \quad \Delta_{FD} = F_1 D_2 - D_1 F_2 \;, \ldots \qquad \text{etc.,}$$

Also

$$\beta = \frac{-(\Delta_{FD} + \Delta_{CB}) \pm \sqrt{(\Delta_{FD} + \Delta_{CB})^2 - 4\,\Delta_{CD}\,\Delta_{FD}}}{2\,\Delta_{CD}} \qquad (1\text{-}17)$$

and by defining

$$R_\beta^2 = (\Delta_{FD} + \Delta_{CB})^2 - 4\,\Delta_{CD}\,\Delta_{FD}$$

one obtains:

$$\beta = \frac{1}{2\,\Delta_{CD}}\left[-(\Delta_{FD} + \Delta_{CB}) \pm R_\beta\right] \qquad (1\text{-}18)$$

In a similar way, eliminate β and obtain

$$\alpha = \frac{1}{2\,\Delta_{BD}}\left[-(\Delta_{FD} + \Delta_{BC}) \pm R_\alpha\right] \qquad (1\text{-}19)$$

where

$$R_\alpha^2 = (\Delta_{BC} + \Delta_{FD})^2 - 4\,\Delta_{BD}\,\Delta_{FC}$$

It can be shown (Hollister, Ref. 1) that $R_\alpha^2 = R_\beta^2$. Call R the common value and obtain

$$\alpha = \frac{1}{2\,\Delta_{BD}}\left[-(\Delta_{FD} + \Delta_{BC}) \pm R\right] \qquad (1\text{-}20)$$

$$\beta = \frac{1}{2\,\Delta_{CD}}\left[-(\Delta_{FD} + \Delta_{CB}) \pm R\right] \qquad (1\text{-}21)$$

Using the fact that $\Delta_{BC} = -\Delta_{CB}$, and from equations (1-20) and (1-21), which represent four possible pairs of solutions, Hollister shows that the only ones which are solutions for the original (1-12) and (1-13) equations in α and β, are

$$\alpha_k = \frac{1}{2\Delta_{BD}}\left[-\left(\Delta_{FD} + \Delta_{BC}\right) + (-1)^{k} R\right] \tag{1-20A}$$

$$\beta_k = \frac{1}{2\Delta_{CD}}\left[-\left(\Delta_{FD} + \Delta_{BC}\right) + (-1)^{k+1} R\right] \tag{1-21A}$$

where $k = 0$ and $k = 1$ give the two possible simultaneous solutions for eq. (1-12) and (1-13).

These are the two basic equations that were used to develop digital computer programs for use in the parameter plane. By fixing ζ or ω_n, one can solve the equation for α and β for particular values of ω_n or ζ respectively, and obtain families of curves of α versus β, used in parameter plane analyses. This basically consists in seeing from these curves which relations should be maintained between α and β to locate the roots of the polynomial in places corresponding to desired undamped frequencies ($\omega_n = \omega_0$) and desired damping ratios ($\zeta = \zeta_0$).

2. Curves with Magnitude as One of the Coordinates

In the present work primary interest is in the curves relating the magnitude of a given transfer function and one of the parameters in the system, for successive values of real frequency ω.

This is obtained as follows (Ref. 1); consider the transfer function for a given physical system

$$G(s) = \frac{q_m s^m + q_{m-1} s^{m-1} + \ldots + q_1 s + q_0}{r_n s^n + r_{n-1} s^{n-1} + \ldots + r_1 s + r_0} \tag{2-1}$$

where coefficients are of the form

$$q_k = l_k \alpha + f_k \beta + g_k \alpha\beta + k_k \tag{2-2}$$

$$r_k = a_k \alpha + b_k \beta + c_k \alpha\beta + d_k \tag{2-3}$$

Then

$$G(s) = \frac{\sum_0^m (l_k \alpha + f_k \beta + g_k \alpha\beta + k_k) s^k}{\sum_0^n (a_p \alpha + b_p \beta + c_p \alpha\beta + d_p) s^p}.$$

To study the real frequency variations, put $s = j\omega$ in the transfer function and obtain

$$G(j\omega) = \frac{\sum_{k=0}^{\overset{\text{even}}{m}} (-1)^{\frac{1}{2}k} \omega^k (l_k \alpha + f_k \beta + g_k \alpha\beta + k_k) + \ldots\ldots}{\sum_{p=0}^{\overset{\text{even}}{n}} (-1)^{\frac{1}{2}p} \omega^p (a_p \alpha + b_p \beta + c_p \alpha\beta + d_p) + \ldots\ldots}$$

$$\frac{\ldots + j \sum_{k=1}^{\overset{\text{odd}}{m}} (-1)^{\frac{1}{2}(k-1)} \omega^k (l_k \alpha + f_k \beta + g_k \alpha\beta + k_k)}{+ j \sum_{p=1}^{\overset{\text{odd}}{n}} (-1)^{\frac{1}{2}(p-1)} \omega^p (a_p \alpha + b_p \beta + c_p \alpha\beta + d_p)} \tag{2-4}$$

For each particular value of ω chosen, ($\omega = \omega_b$), the following definitions are made:

$$A_r \triangleq \sum_{p=0}^{\overset{\text{even}}{r}} (-1)^{\frac{1}{2}p} \omega_b^{r} a_p \quad ; \qquad B_r \triangleq \sum_{p=0}^{\overset{\text{even}}{r}} (-1)^{\frac{1}{2}p} \omega_b^{r} b_r$$

and similarly for C_r, D_r ;

$$A_i \triangleq \sum_{p=1}^{\overset{\text{odd}}{m}} (-1)^{\frac{1}{2}(p-1)} \omega_b^{r} a_p \quad ; \qquad B_i \triangleq \quad \ldots$$

and similarly for C_i, D_i.

$$E_r \triangleq \sum_{k=0}^{\overset{\text{even}}{m}} (-1)^{\frac{1}{2}k} \omega_b^{r} e_k ; \quad \text{and similarly for } F_r, G_r, H_r$$

and

$$E_i = \sum_{k=1}^{\overset{\text{odd}}{m}} (-1)^{\frac{1}{2}(k-1)} \omega_b^{k} e_k \quad \text{and similarly for } F_i, G_i, H_i .$$

Finally there results:

$$G(j\omega_o) = \frac{[\alpha E_r + \beta F_r + \alpha\beta G_r + H_r] + j[\alpha E_i + \beta F_i + \alpha\beta G_i + H_i]}{[\alpha A_r + \beta B_r + \alpha\beta G_r + D_r] + j[\alpha A_i + \beta B_i + \alpha\beta C_i + D_i]} \tag{2-5}$$

Performing $G(j\omega_b) \cdot G(-j\omega_b)$ one obtains the magnitude of the transfer function defined by

$$M^2 = |G(j\omega_b)|^2$$

$$M^2 = \frac{(\alpha E_r + \beta F_r + \alpha\beta G_r + H_r)^2 + (\alpha E_i + \beta F_i + \alpha\beta G_i + H_i)^2}{(\alpha A_r + \beta B_r + \alpha\beta C_r + D_r)^2 + (\alpha A_i + \beta B_i + \alpha\beta C_i + D_i)^2} \tag{2-6}$$

These manipulations provide an equation in α and β for M^2, which has the general form

$$\Phi(\alpha,\beta) - \left[M^2 \cdot \Theta(\alpha,\beta)\right] = 0$$

and by expanding each of the components of (2-6) and isolating β (as a chosen variable parameter) there results:

$$(M^2 R_1 - R_2)\beta^2 + (M^2 W_1 - W_2)\beta + M^2 V_1 - V_2 = 0 \tag{2-7}$$

where $R_1 = (B_r^2 + B_i^2) + 2\alpha(B_r C_r + B_i C_i) + \alpha^2(C_r^2 + C_i^2)$

$$R_2 = (F_r^2 + F_i^2) + 2\alpha(F_r G_r + F_i G_i) + \alpha^2(G_r^2 + G_i^2)$$

$$W_1 = 2(B_r D_r + D_i B_i) + 2\alpha(A_r B_r + A_i B_i + C_i D_i + C_r D_r) + \\ + 2\alpha^2(A_r C_r + A_i C_i)$$

$$W_2 = 2(F_r H_r + F_i H_i) + 2\alpha(E_r F_r + E_i F_i + G_r H_r + G_i H_i) + \\ + 2\alpha^2(E_r G_r + E_i G_i)$$

$$V_1 = (D_r^2 + D_i^2) + 2\alpha(A_r D_r + A_i D_i) + \alpha^2(A_r^2 + A_i^2)$$

$$V_2 = (H_r^2 + H_i^2) + 2\alpha(E_r H_r + E_i H_i) + \alpha^2(E_r^2 + E_i^2)$$

As the final step, solve the quadratic equation for β and obtain

$$\beta_{1,2} = \frac{-(M^2W_1 - W_2) \pm \sqrt{(M^2W_1 - W_2)^2 - 4(M^2R_1 - R_2)(M^2V_1 - V_2)}}{2(M^2R_1 - R_2)} \qquad (2\text{-}8)$$

As was stated earlier, equations 1-20A and 1-21A could be used to write digital computer programs for parameter plane analysis. The same may be said of equation 2-8, which provides the possibility of obtaining a family of constant frequency curves of voltage magnitude versus one of the original parameters α or β, or any combination of the four variables (α, β, M and ω) by fixing one of them and combining the other three in any desired way.

This was in fact the work of Rommel and Cradit (Reference 4) which prepared computer programs designed to give the possible different plots resulting from the combination of the four variables referred to above, and Glavis (Reference 3) who perfected these programs and combined them into one unique deck prepared to give any combination of parameters or variables which may be of interest (See Appendix I).

This program, which was used in the preparation of this thesis, is included as Appendix I PARAMS (Digital Computer Program). Using it, frequency curves are obtained for magnitude as function of one of the parameters, maintaining the other parameter fixed; this corresponds to the PARAM 5 Part of the program cited above.

3. Application of Parameter Plane Curves to Frequency Response.

Having already available a computer program to solve the system transfer function and determine its magnitude-versus-frequency response did not solve all the questions about obtaining plots for analysis of systems from the respective transfer functions, because all the programs were prepared for work on cases where all the elements are time invariant.

The task of predicting the response of a system with nonlinear elements, or even time-variant elements, was not easy to solve analytically. Therefore, it was thought that the parameter plane curves of the PARAM 5 type (voltage magnitude versus one of the parameters, with ω varying from curve to curve) could be used to obtain quickly the frequency response, by graphically reading the values of voltage magnitude corresponding to the particular value of the parameter where it intersects each frequency curve, and plotting a new graph of magnitude versus frequency, for that particular value of the parameter.

This procedure also makes it very practical to use the graphical representation of the nonlinearity if it happens to be a function of the magnitude, and by use of superposition of graphs, to obtain the frequency response for the nonlinear cases.

The purpose of this work is to show how this is done, by means of some examples for the case of electrical networks, and to prove that the method is good in the solution of this type of problem, giving results which may be considered within acceptable accuracy.

3.1 Description of the Method.

The method described here to obtain the frequency response of electrical networks containing one nonlinear element, may be summarized as follows:

1. Obtain the transfer function of the network, in terms of output function as a function of the input. The most direct application of the method occurs when the nonlinearity present is a function of the magnitude of the voltage across it (for example, temperature-sensitive resistors or voltage-sensitive capacitors). This voltage is the output function wanted as a function of frequency.

2. Obtain a family of curves in values of frequency (one for each fixed frequency) for the magnitude of the output as function of the nonlinearity element values. This nonlinearity should be allowed to vary along a range that includes the values that are going to be read when it is expressed as a function of the magnitude of the voltage across its terminals.

These curves may be obtained by hand computation or computer computation of the mangitude of the output function, for a certain input, using successive fixed values of the nonlinearity, which is treated as a parameter. Using a computer program it is very practical to obtain these families of curves and the graphical method leads very simply to the frequency response plot.

3. Having obtained the "parameter versus magnitude" curves, it can be seen that for each fixed value of the parameter (which is represented in the graph by a line perpendicular to the parameter axis, and intersecting it at the chosen value), the magnitude values of the output function are given by reading the points along the magnitude axis corresponding to the intersection of the line representing the parameter value with each one of the curves of the frequency family.

4. It was this concept that lead to the idea that the graph could be used to read values of magnitude corresponding to the intersection of the frequency curves with any value of the parameter, in such

a way that if the parameter could be expressed as a function of the magnitude in a graphical manner (this for the case of nonlinear variation of the parameter), and superimposed on the parameter plane curves, the frequency response of the network could be obtained by reading it directly from this graphical display.

5. This is in fact what was done, and the present work includes several types of networks with different nonlinearities to which the method was applied. At the same time the frequency response of these networks was obtained by means of simulation using a digital computer and the system IMB DSL 360.

The results obtained, as was stated before, may be considered to fall within acceptable accuracy.

6. The examples that follow show the method used in some networks of general use, and the relationships between the parameter and the voltage across its terminals does not correspond, in some cases, to that most likely to be encountered (example, negative temperature coefficient resistors). This was done to cover a large variety of functions, in the general sense, and as a way of illustration.

Also, the cases considered have normalized values for components, as a means of simplification.

3.2 Examples of Application of the Method.

3.2.1 Second Order Network (Band-pass filter)

The first case considered was the following network, (Fig. 3.1), in which the output resistor was a nonlinear function of the voltage across its terminals.

The values used are normalized and the input voltage is considered to be a pure sinusoid of magnitude unity.

Consider the network:

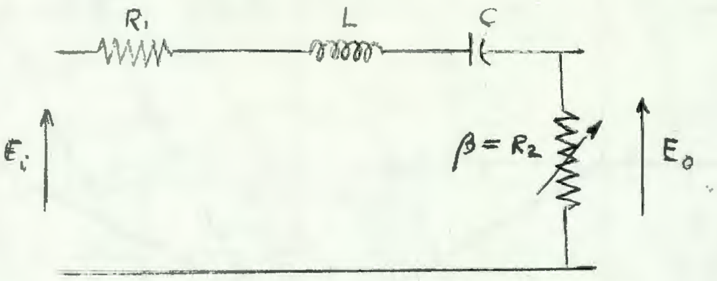

Fig. 3.1 Band-pass Network

Using normalized values for R , L and C it can be seen that its transfer function is:

$$T(s) = \frac{E_o(s)}{E_i(s)} = \frac{R_2}{(R_2 + R_1) + sL + 1/sC}$$

or

$$T(s) = \frac{R_2 C s}{(R_2 + R_1)Cs + s^2 LC + 1} = \frac{C\beta s}{LCs^2 + (\beta + R_1)Cs + 1}$$

or

$$T(s) = \frac{s\beta}{s^2 + (\beta + 1)s + 1}$$

where

$$R_1 = 1, \quad L = 1, \quad C = 1.$$

One of these elements may be used as the constant parameter $\propto$ for PARAM 5 program purposes.

Using equations (2-5) and (2-6):

$$m^2 = T(j\omega) \cdot T(-j\omega) = \frac{\omega^2 \beta^2}{(1 - \omega^2)^2 + (\beta +)^2 \omega^2}$$

This equation is the one that could be used to obtain the "magnitude versus β" curves, for successive values of frequency ω . In this work the PARAM 5 Program was used and the graph obtained shows β varying from 0 to 4.0 while the magnitude of the output voltage goes from 0 to 8, and is shown on Fig. 3.2.

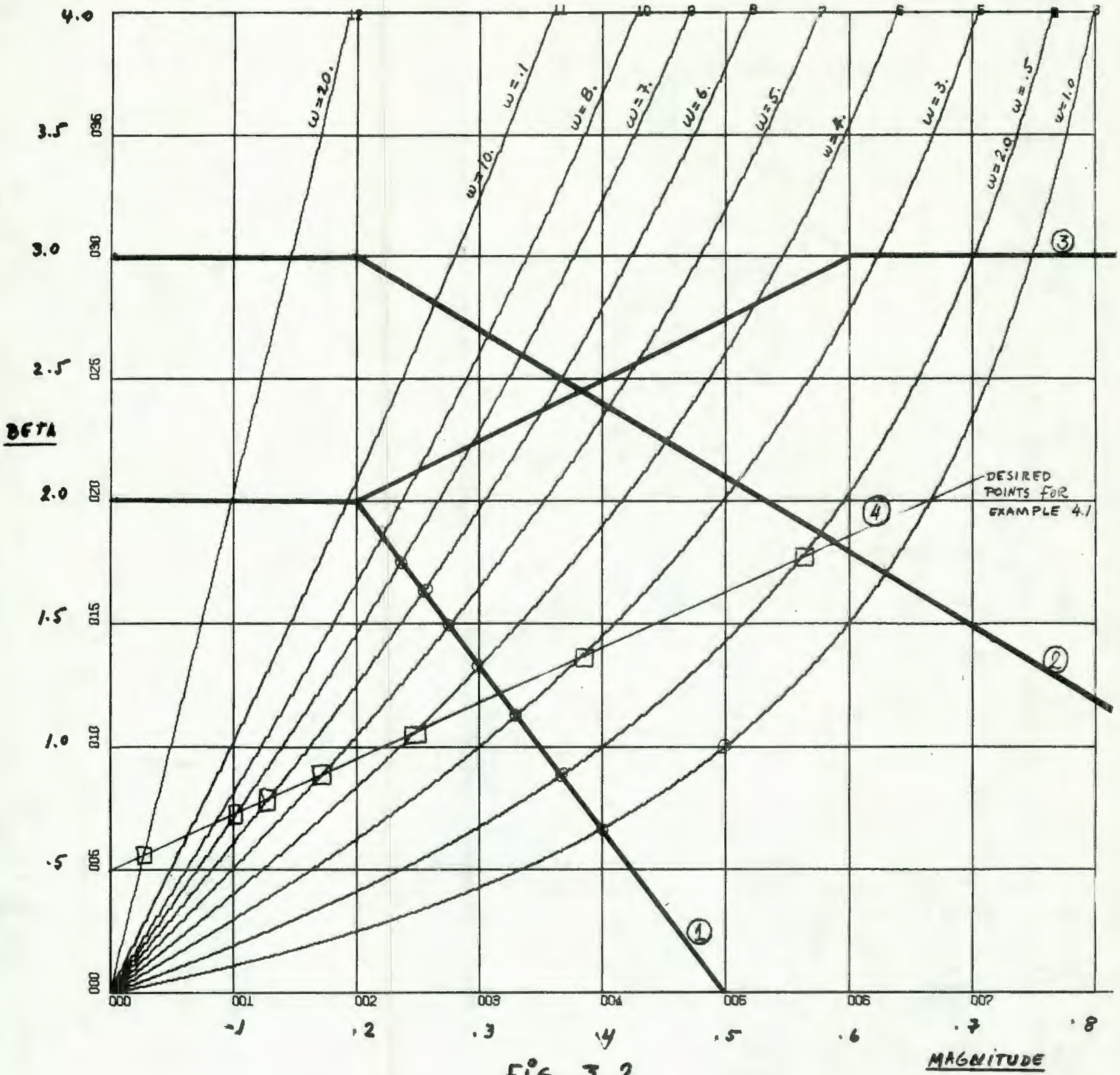

FiG. 3.2

X-SCALE=1.00E-01 UNITS INCH.
Y-SCALE=5.00E-01 UNITS INCH.

RUIVO BAND PASS NET.
OMEGA CURVES MAG. VS. BETA

$$T(s) = \frac{s\,\beta}{s^2 + (\beta+1)s + 1}$$

After the graph was obtained, three cases of possible nonlinear variations of β with voltage were considered, and their graphical representation superimposed on the main graph. The values obtained by reading the magnitude corresponding to each intersection of the β lines with the frequency curves were plotted to obtain the magnitude-versus-frequency curve which in fact corresponds to the frequency response of the network.

The same cases were simulated using digital simulation, and the results obtained for the frequency response are also shown.

First Nonlinearity

The first nonlinearity considered was of the type shown,

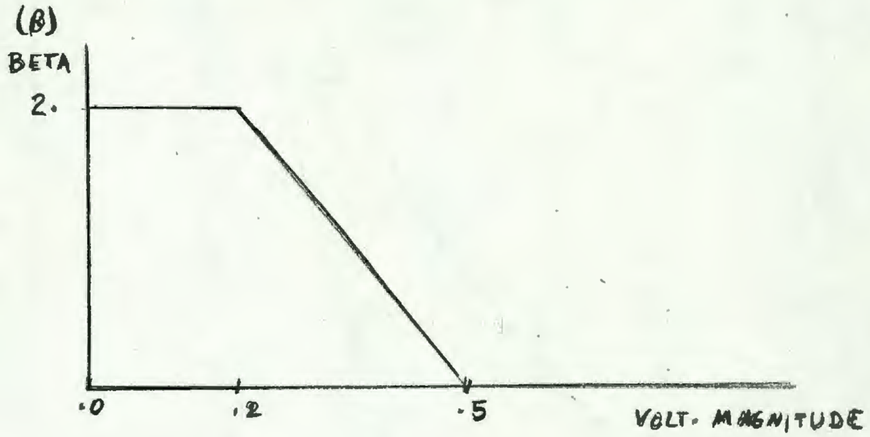

Fig. 3.3 Beta as Nonlinear Function of Magnitude

in which β is considered to maintain a constant value of 2, until the instantaneous magnitude of the voltage is 0.2, and after that to decrease constantly with a slope of -2/.3.

The results obtained are tabulated and presented on the graph on Fig. 3.4.

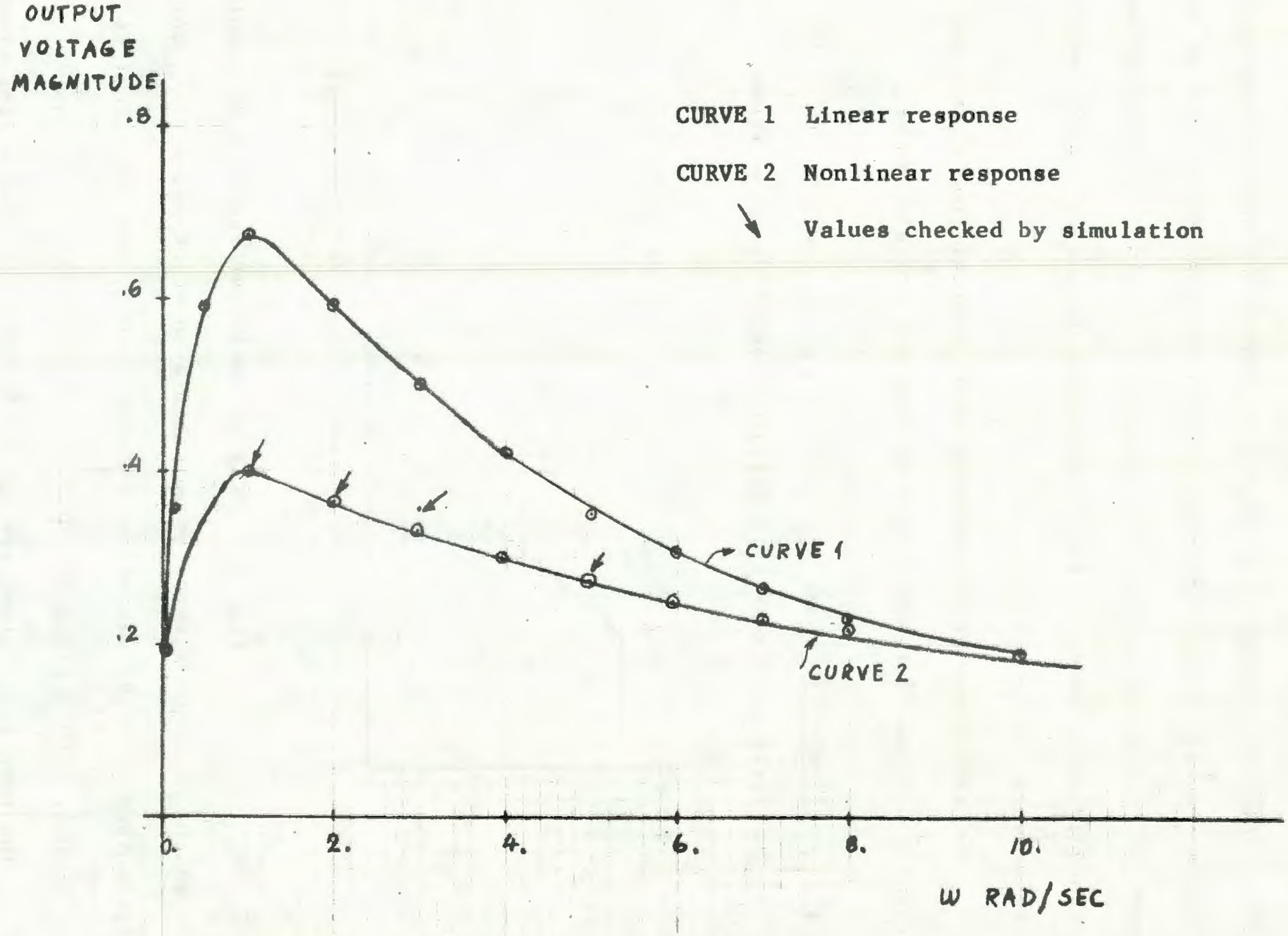

Fig. 3.4 Frequency response of nonlinear band-pass network (CASE 1)

Obtained values for frequency response of band pass network

ω (freq. Rad/Sec)	Output Magnitude PARAM 5 Graphical Method	Output Magnitude Simulation
1.0	.40	.417
2.0	.370	.398
3.0	.335	.373
5.0	.280	.300

Second nonlinearity

The second case considered, using the same network, was of the same type but with a different variation for β.

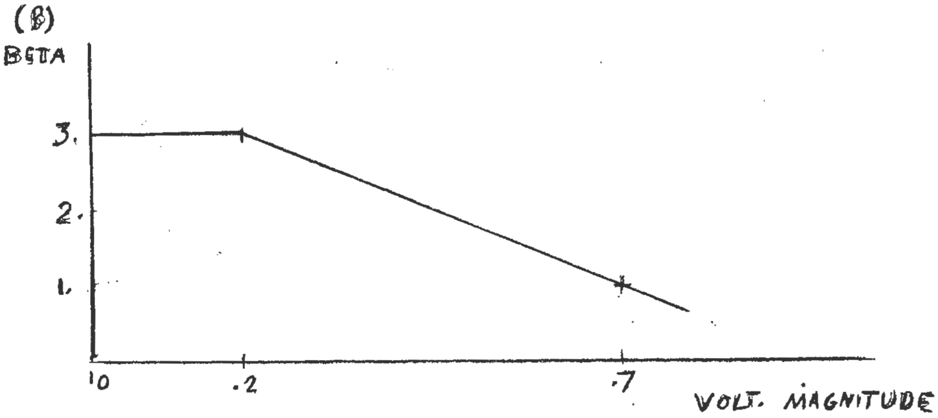

Fig. 3.5 Beta as nonlinear function of magnitude

The slope now is $\frac{-2}{.5}$ and the initial value for β is 3.0. The results obtained follow, and the corresponding graph is included as Fig. 3.7.

(freq. Rad/Sec) ω	Output Voltage Magnitude (PARAM 5)	Output Voltage Magnitude (Simulat.)
1.0	.625	.618
2.0	.575	.565
4.0	.450	.440
5.0	.405	.400

Third Nonlinearity

The third case considered, with the same network, shows the behavior of the filter with the nonlinear element increasing its value with higher values of voltage

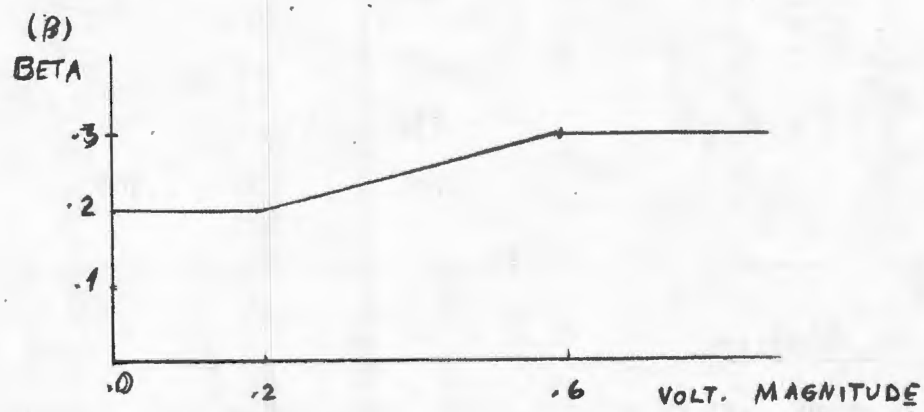

Fig. 3.6. Beta as Nonlinear Function of Magnitude

The results obtained by simulation and graphical methods are as follows, and the corresponding graph is included as Fig. 3.8.

Frequency Response of Band Pass Net. for Third Nonlinearity

ω Freq. (Rad/Sec)	Output Voltage Magnitude (Simulation)	Output Voltage Magnitude (PARAM 5)
1.2	.75	.75
2.0	.713	.70
4.0	.55	.52
5.0	.43	.43

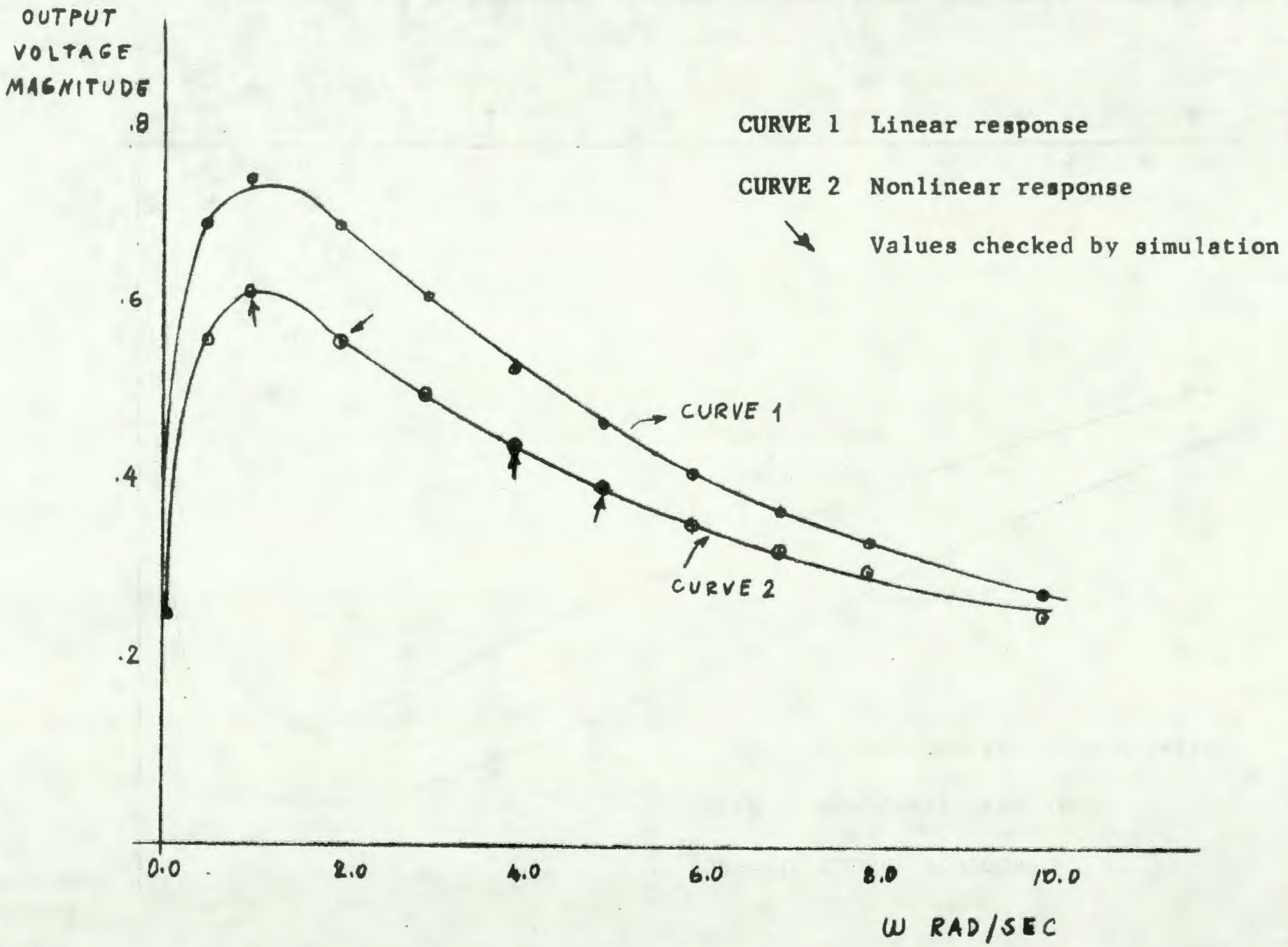

Fig. 3.7 Frequency response of nonlinear band-pass network (CASE 2)

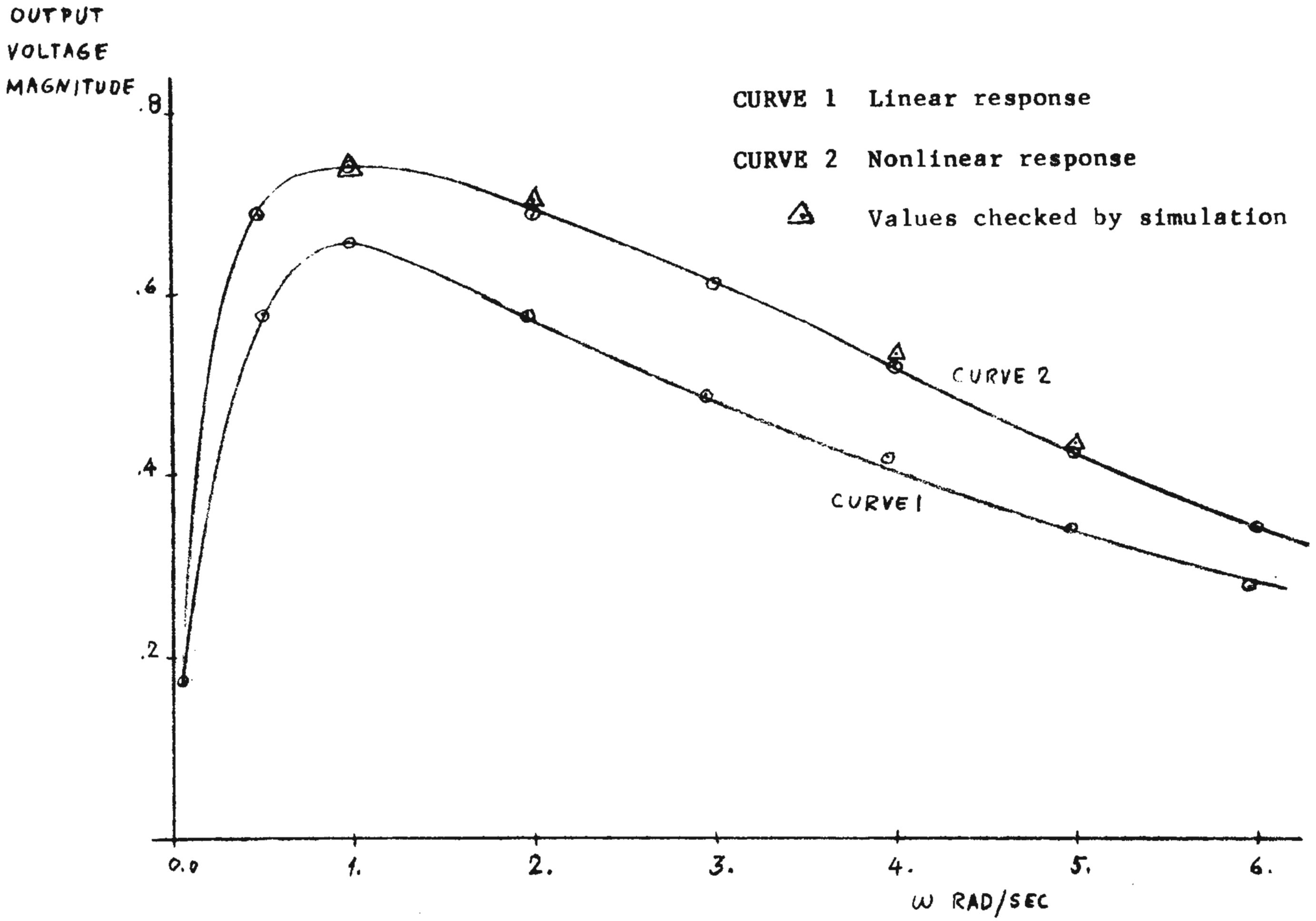

Fig. 3.8 Frequency response of nonlinear band-pass network (CASE 3)

4. Use of the Method in the Shaping of Network Responses.

One area that may be considered of interest is the possibility of use of the present method and parameter plane curves to find what kind of nonlinear element should be introduced in a network in order to obtain a certain frequency response, different from that obtained with linear elements in the network.

For a case like this, after obtaining the linear frequency response it may be seen from the respective graphical display that a somewhat different curve shape is desired, corresponding to a different frequency response. This desired response may be superimposed on the parameter plane, by plotting the magnitude-versus-frequency values that correspond to it.

Once in the parameter plane, these points define a curve for the parameter in terms of magnitude of the response, and may be used to approximate a nonlinear function which would express the parameter in terms of magnitude. Such a nonlinear element, if inserted in the network, would provide the frequency response which originated the same functional relationship.

The degree of accuracy and the closeness between the desired values and those obtained depend on the approximations made when expressing the parameter in terms of magnitude in order to make it correspond to the series of points transported from the frequency response plane.

This method will be illustrated with the following examples:

4.1 Reshaping of frequency response curve of a band-pass network, by introduction of a nonlinearity.

Consider the network used in example 3.3.1; the frequency response for this network is easily obtained by the graphical method explained previously and is shown in the graph in Fig. 4.2, for linear values of the elements. In this case it was considered that the output resistor had the invariant value of 2.0 units, and the curve obtained is referred to as number 1.

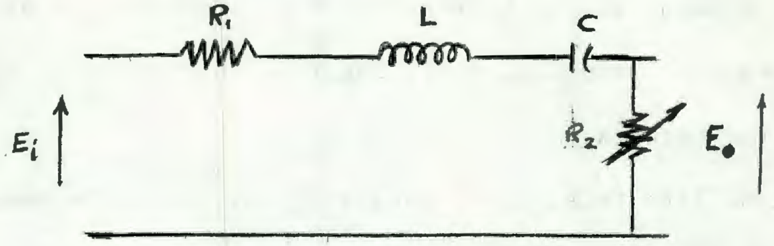

Fig. 4.1 Network Considered in the Present Example

If it is desired to sharpen the response of the present network to a different curve, as for example the one indicated in the graph of Fig. 4.2, curve 2, the points may be taken from the new curve and transported to the parameter plane, and plotted there.

This was done in the graph on Fig. 4.2, as indicated by curve nº 2, and the points corresponding to the desired response were plotted in curve nº 4 on the graph on Fig. 3.2, which refers to the network being considered. These points are indicated by the symbol ⊡ .

The relationship between magnitude of voltage and values of non-linearity were read from this same graph.

This having been done, it was decided to use the linear, time-variant resistor R_2 as a time-variant element, defined by the following equation of a straight line in the parameter plane:

$$R_2 = (\text{output voltage magnitude}) \times 2.22 + .5 \qquad (4\text{-}1)$$

It may be seen that if the output resistor really behaves in accordance with equation 4-1, the frequency response is the desired curve, when transported back to the frequency-response graph.

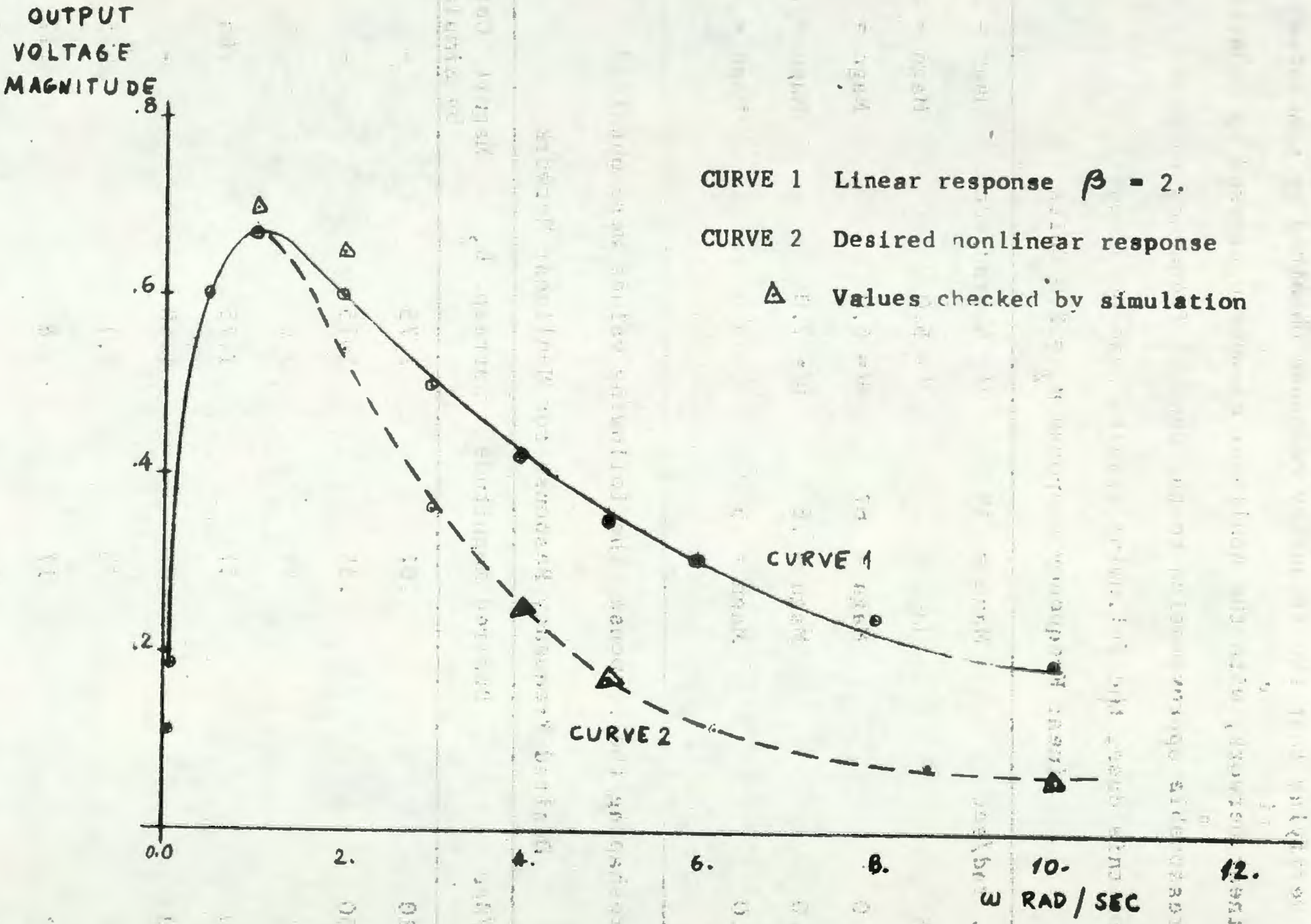

Fig. 4.2 Frequency response of band-pass network

The present example was checked by the use of digital simulation, and by verifying that the frequency response obtained by simulation of a nonlinear network, with the nonlinear element expressed by equation 4-1, was a reasonable approximation to the desired frequency response.

For this case, the following results were obtained:

Linear Frequency Response R_2 = 2.0 Units

ω = 1. rad/sec	Magn = .19	ω = 4. rad/sec	Magn = .42
ω = .5	Magn = .6	ω = 5.0	Magn = .35
ω = 1.0	Magn = .67	ω = 6.0	Magn = .305
ω = 2.0	Magn = .6	ω = 7.0	Magn = .27
ω = 3.0	Magn = .5	ω = 8.0	Magn = .24

After reshaping the response, the following values were obtained

Desired Frequency Response for Nonlinear Network

ω Rad/Sec	Desired Magnitude	Corresp. R_2	Magnit. Obtained by Simulation
.10	.07	1.75	-
.50	.55	1.75	-
1.0	.67	2.0	.71
2.0	.57	1.75	.65
3.0	.48	1.40	-
4.0	.25	1.1	.25
5.0	.17	.8	.17
10.0	.07	-	.07
20.0	.03	.55	-

4.2 Frequency Response and its Reshaping, for a low-pass Filter with Load

As another illustration consider the following network.

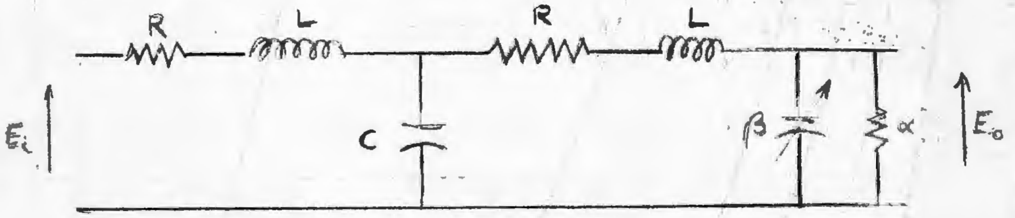

Fig. 4.3 Second Order Low-Pass Filter

with two possible variable parameters, α and β, or with a variable parameter β which could be used in conjunction with a different load α for each case.

The transfer function is obtained as:

$$T(s) = \frac{E_0(s)}{E_i(s)} = \frac{\alpha}{2R + \alpha + s\left[2\alpha\beta R + 2L + CR^2 + CR\alpha\right] + s^2\left[2\alpha\beta L + CR^2\alpha\beta + 2LCR + LC\alpha\right] + s^3\left[2LCR\alpha\beta + L^2C\right] + s^4\left[\alpha\beta L^2 C\right]} \quad (4\text{-}2)$$

It is desired to analyze the transfer function behavior, or the frequency response for a particular value of α when β is a nonlinear function of the output voltage. This can be done by the PARAM 5 method previously explained, and the following results were obtained for the simplified case, with all values normalized, in which

$C = 1$ $L = 1$ $R = 1$

The transfer function becomes:

$$T(s) = \frac{\alpha}{2 + \alpha + s\left[2\alpha\beta + 3 + \alpha\right] + s^2\left[3\alpha\beta + 2 + \alpha\right] + s^3\left[2\alpha\beta + 1\right] + s^4\left[\alpha\beta\right]} \quad (4\text{-}3)$$

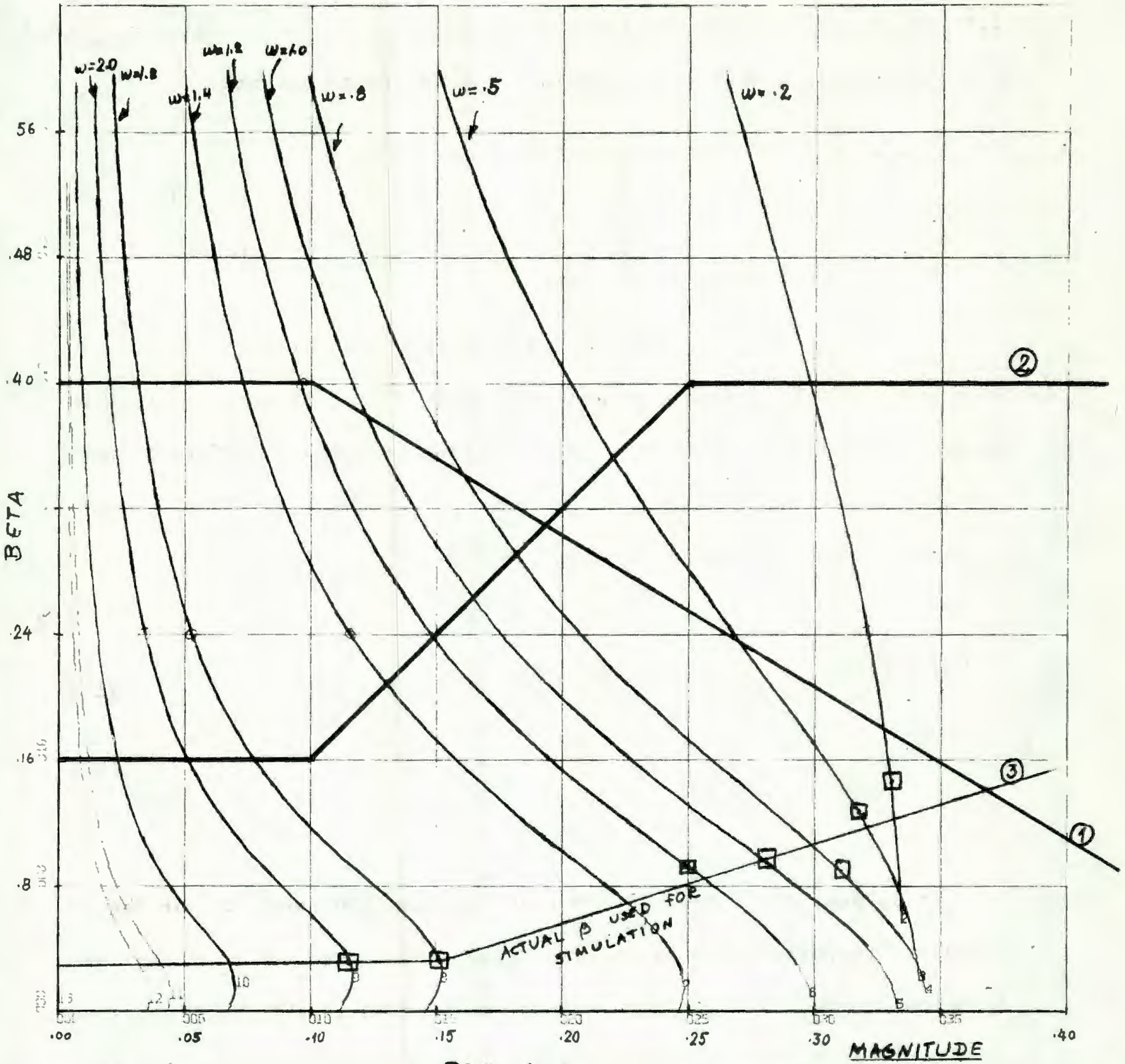

FIG. 4.4.

$$T(s) = \frac{1}{3+s[2\beta+4]+s^2[3\beta+3]+s^3[2\beta+1]+s^4 3}$$

X-SCALE=5.00E-02 UNITS INCH.
Y-SCALE=8.00E-01 UNITS INCH.
RUIVO L.P. NET. 2 SEC. AND LOAD
OMEGA CUR. MAG. VS. BETA

and for $\alpha = 1$, this reduces to:

$$T(s) = \frac{1}{3 + s[2\beta + 4] + s^2[3\beta + 3] + s^3[2\beta + 1] + s^4[\beta]} \tag{4-4}$$

Using Eq. 4-4 for the parameter plane program the curves relating and magnitude of output voltage were obtained. Two cases were considered, one for each type of nonlinear behavior of β , as shown on the graph on Fig. 4.4.

4.2.1 For the first case consider β as a function of magnitude of output voltage, as given by the following relationship:

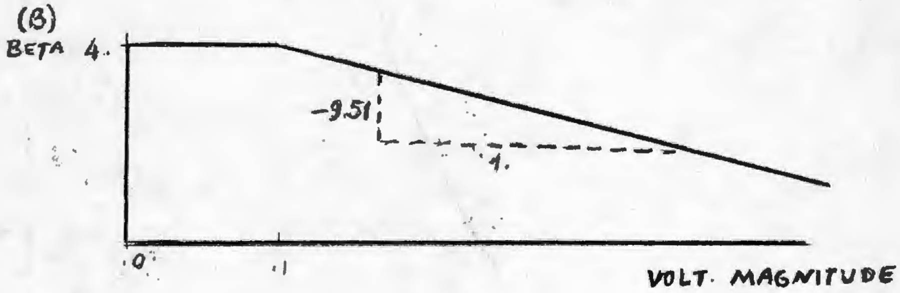

Fig. 4.5 Beta As Nonlinear Function of Voltage Magnitude

Beta (β) = 4 (for output voltage magnitude $\leq$ .1)

or Beta (β) = -9.51 x (output voltage magnitude) + 4.951

Employing the usual procedure of superimposing this graphical relationship on the parameter plane curves, (curve 1) the frequency response was obtained and the results checked by simulation of the network, with the graphical presentation included as Fig. 4.6.

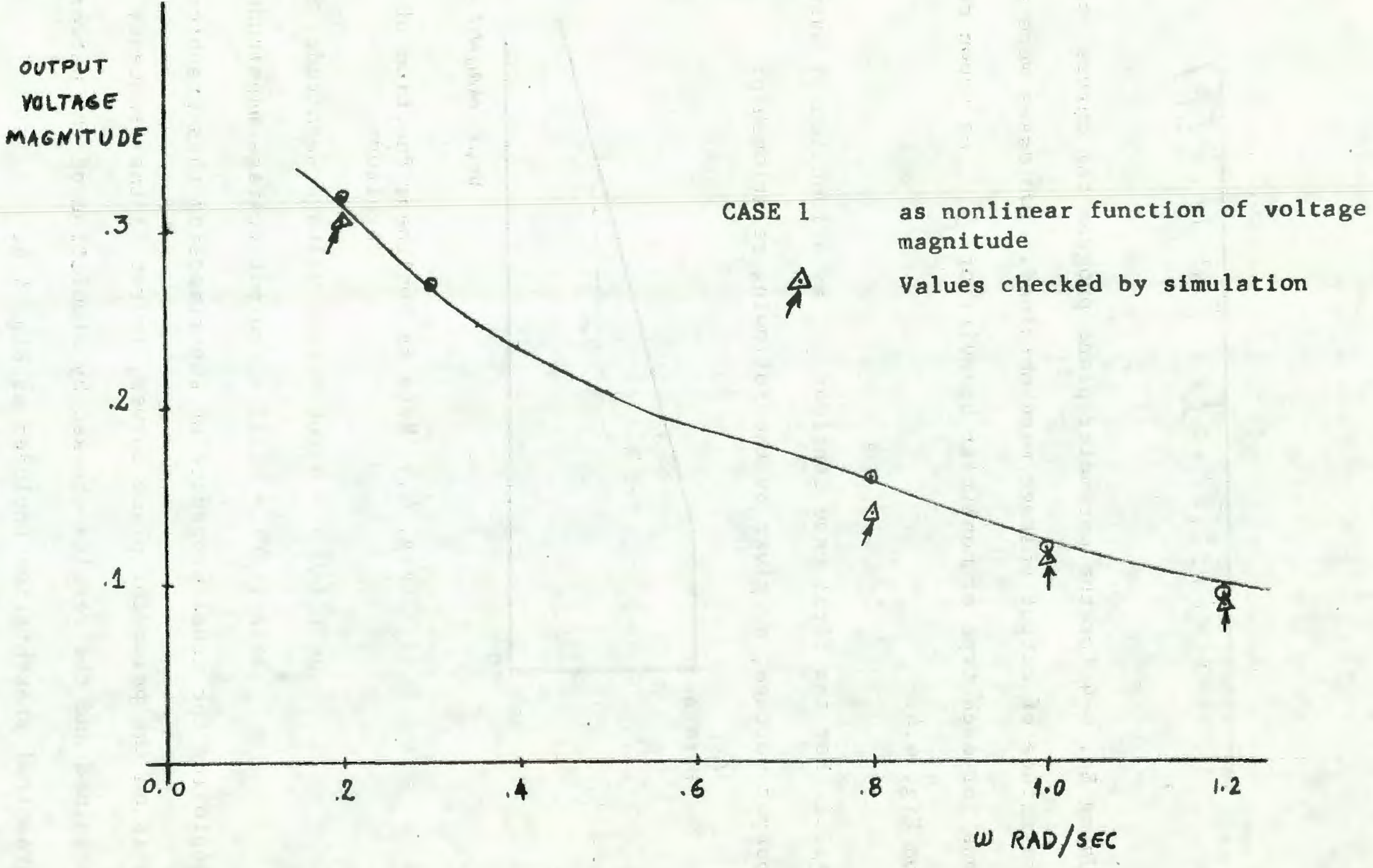

Fig. 4.6 Frequency response of a two-section low-pass Network

Results Obtained for Freq. Response of a 2-section Low-pass Network

Case 1

ω Rad/sec	Out. Volt. Magnitude (Parameter Plane)	Out. Volt. Magnitude (Simulation)
.2	.325	.310
.8	.158	.148
1.0	.120	.119
1.2	.095	.0961
2.0	.02	.0207

The above results are plotted in the graph on Fig. 4.6, and are considered to be a reasonably good approximation.

4.2.2

As a second illustration consider a different type of nonlinearity for β.

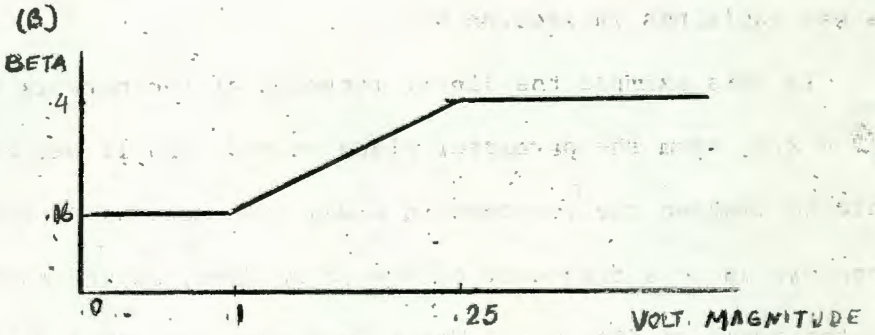

Fig. 4.7 Beta as Nonlinear Function of Magnitude

As shown above, β is defined by the equations:

β = .17 for output voltage magnitude $\leq .1$

β = .16 x (out. voltage magn.) for $.1 \leq$ output voltage magnitude $\leq .25$

β = .4 for out. voltage magnitude $> .25$

Using the usual method the following results were obtained from the graph on Fig. 4.4, (Curve 2).

Results obtained for Freq. Response of a two-section, low-pass network

Case 2

ω rad/sec	Out.Volt. Magnitude (Param. Plane)	Out.Volt. Magnitude (Simulation)
.2	.295	.313
.8	.180	.208
1.0	.170	.174
1.2	.150	.160
2.0	.050	.050
2.4	.020	.023

These results are displayed on the following graph, on Fig. 4.8.

4.2.3 Reshaping of Response of Networks.

Now consider the possibility of using the method as a means of changing the response of the network by introduction of a nonlinearity, as was explained in Section 4.1.

In this example the linear response of the network was obtained for $\beta = 2.4$, from the parameter plane curves, and it was considered desirable to flatten the response in a way that would give constant magnitude response up to a frequency of $\omega = .8$ rad/sec, as indicated by Curve No. 2 in the graph on Fig. 4.9. The points read from this curve were transported to the parameter plane graph and plotted as ⊡. It was chosen to approximate them by two segments of straight line as shown by curve 3. The resulting frequency response for the approximation of β as a function of output voltage was plotted in the graph on Fig. 4.9, indicating that the network had in fact a response reasonably close to what was desired.

The defined relationship between β and output voltage was simulated and the results obtained are shown in the following table.

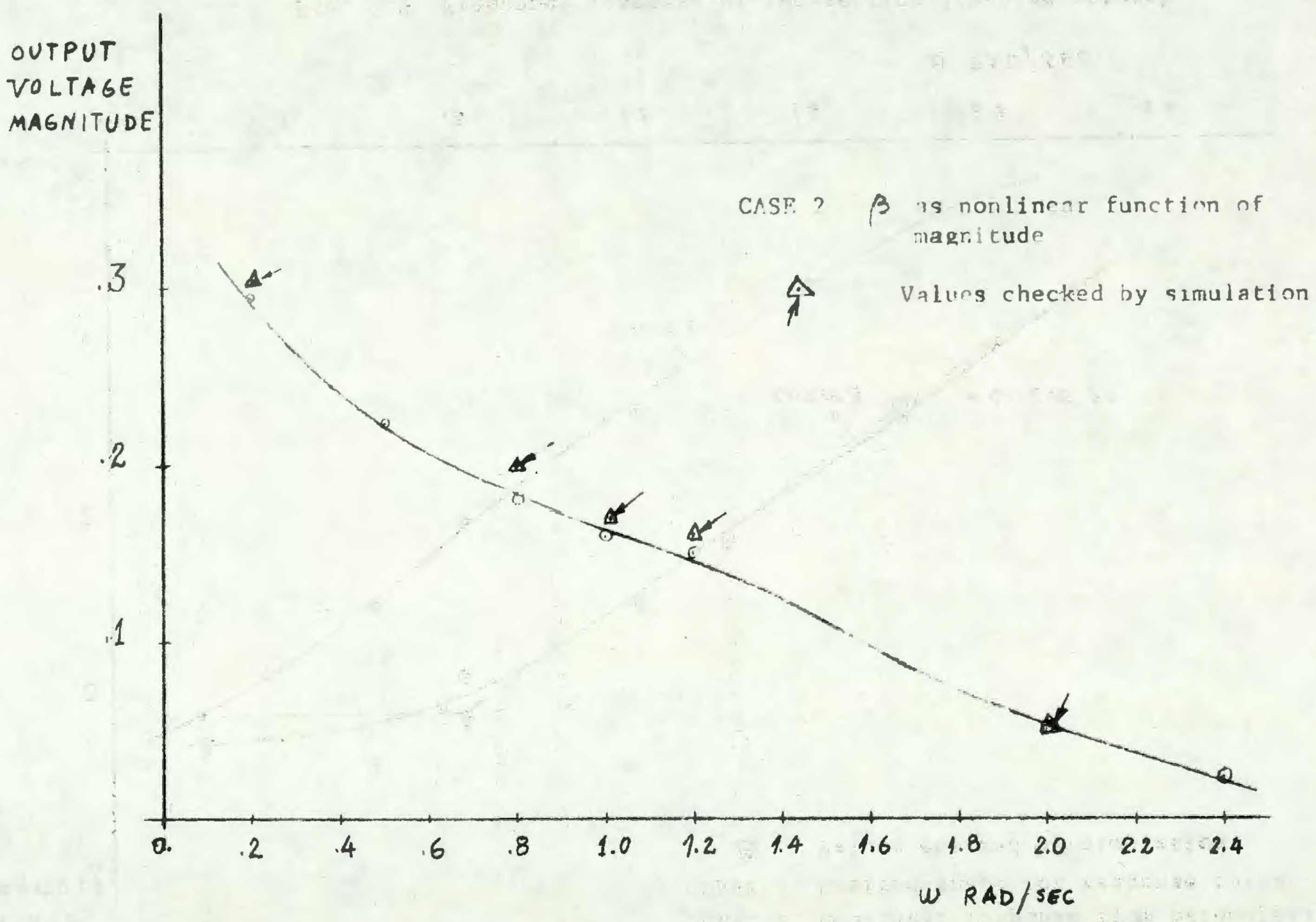

Fig. 4.8 Frequency response of a two-section low-pass network

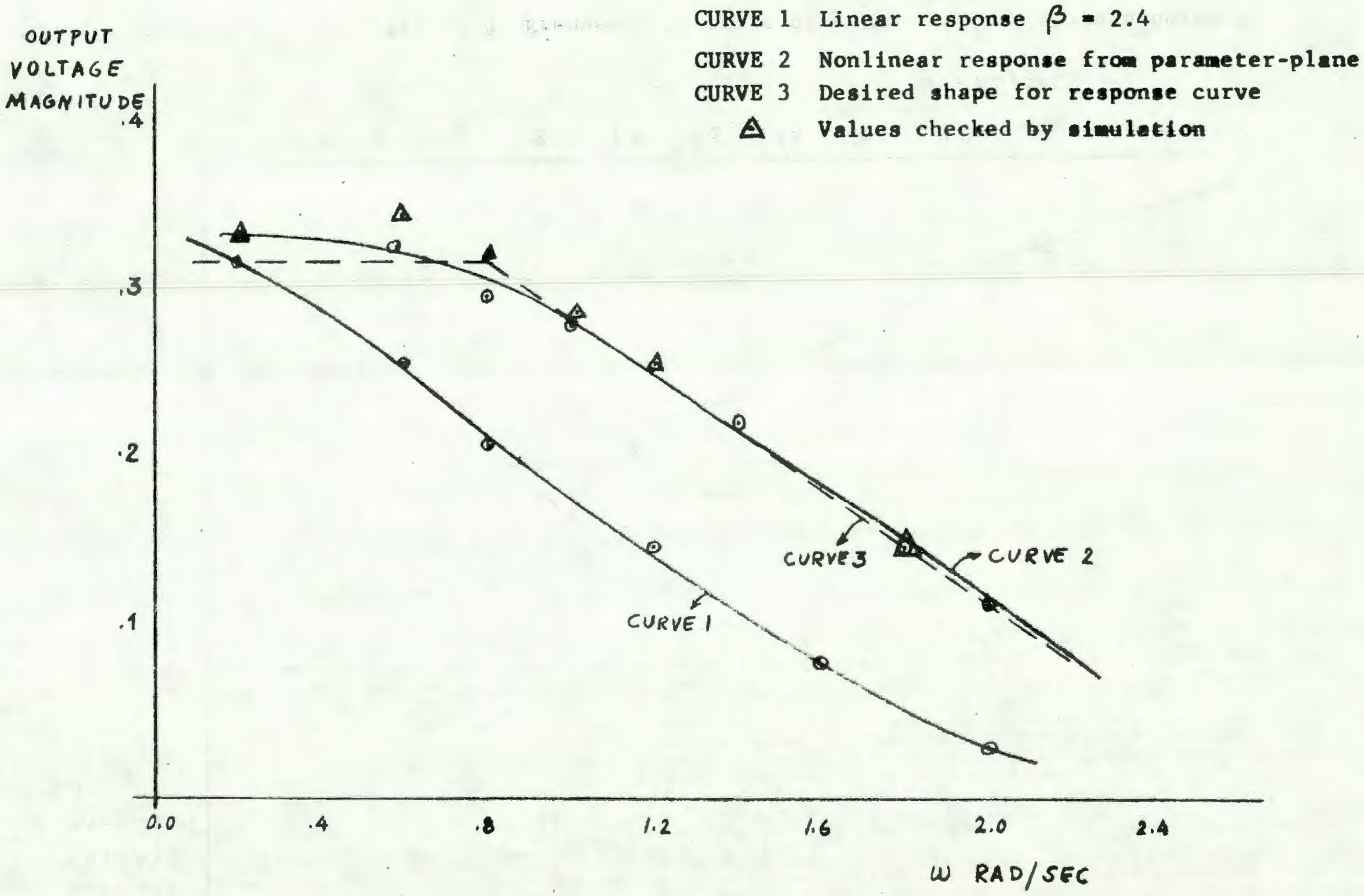

Fig. 4.9 Frequency response of two-section low-pass network with load

Results Obtained in Reshaping the Frequency Response of a Section Low-Pass Filter

ω rad/sec	Desired Magnitude Response	Act. Introd. Value of β	Expected Response from Param. Plane	Obtained Response (by simulation)
.2	.325	β = -.48 +5.2x(output voltage magnitude)	.335	.335
.5	.325		.330	.350
.8	.325		.30	.330
1.0	.275		.275	.280
1.2	.250		.252	.252
1.4	.225		.225	--
1.8	.150	.3	.150	.150
2.0	.120	.3	.120	--

5. Frequency Response of Networks with Output Voltage not Directly Related to the Nonlinear Element.

As an extension of the present work, the case can be considered where the nonlinear element is not directly across the output voltage, but may instead be in any other place in the network.

It can be seen that in a case of this kind, the method cannot be applied directly, but instead can be used to determine the values that the nonlinear element will take on as a function of the input voltage. Then using these values for a point-by-point solution of the main transfer function of ultimate interest, the frequency response of the network can be determined.

To do this, a secondary transfer function is defined, relating the input voltage and the voltage across the nonlinearity, and is used in a parameter plane context to obtain the nonlinearity as a function of frequency (and consequently of the voltage magnitude across itself). This is accomplished by superposition of the graphical relationship between the nonlinear element and the voltage across it on the parameter-plane frequency curves, as was done before.

With this relation between frequency and the value of the nonlinear element, it is possible to enter the main transfer function relating input voltage to output voltage, and compute output voltage for each frequency.

5.1 Indirect Nonlinear Frequency Response.

As an illustration, consider the network for which C is considered

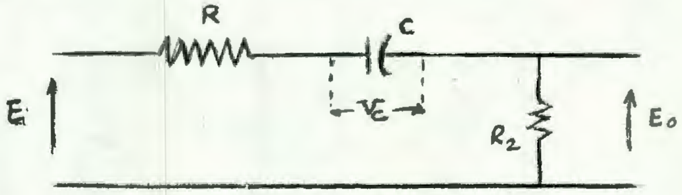

Fig. 5.1 Network for Indirect Response

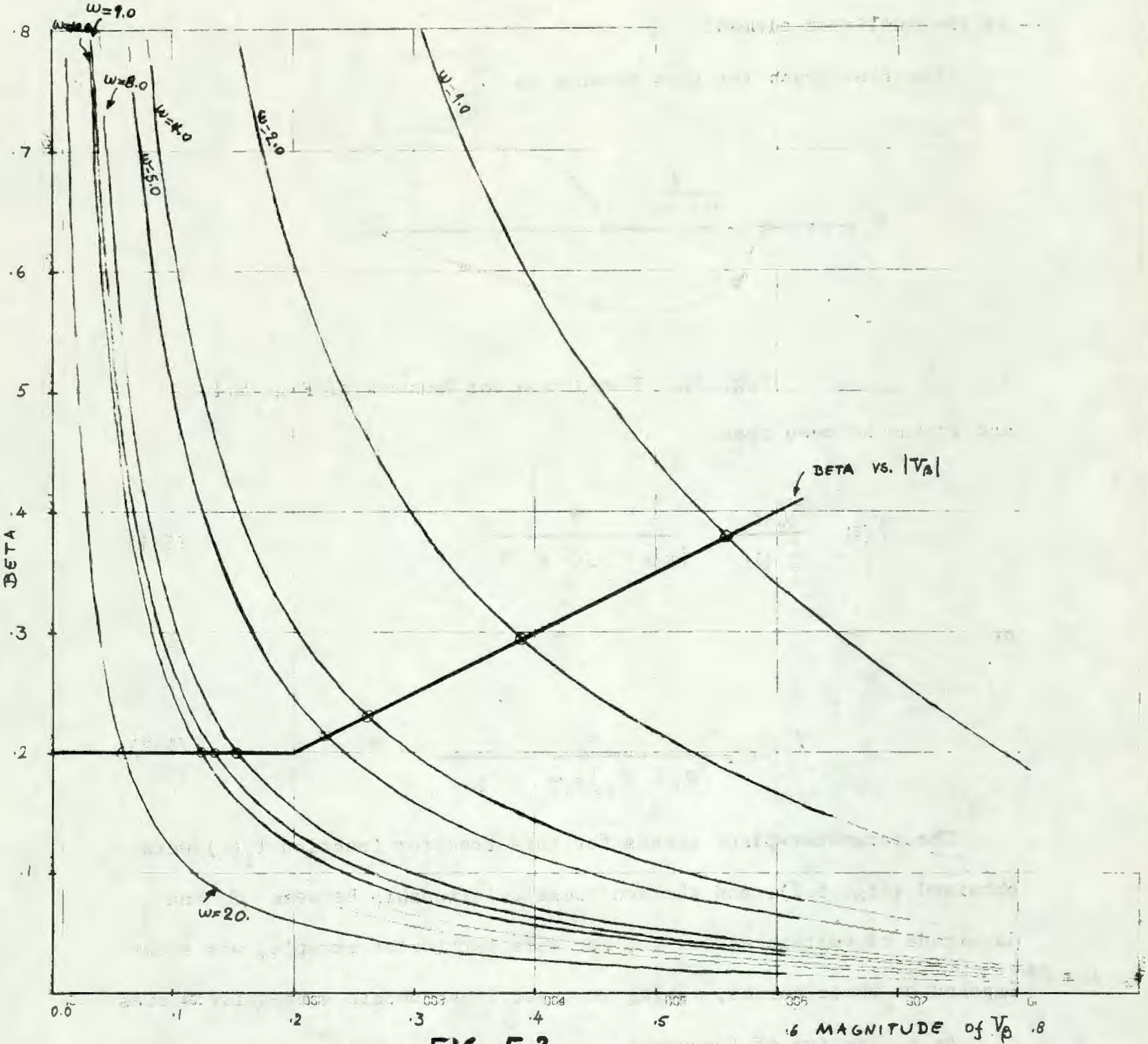

FIG 5.2

X-SCALE=1.00E-01 UNITS INCH.
Y-SCALE=1.00E-01 UNITS INCH.
RUIVO (IND. N. LIN. CASE1)
BETA VS. MAG.

$$\boxed{T_1(s) = \frac{1}{4s/\beta + 1}}$$

as the nonlinear element, β.

The flow graph for this network is

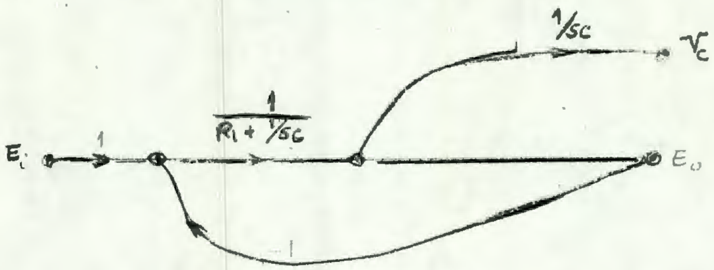

Fig. 5.3 Flow Graph for Network of Fig. 5.1

and it can be seen that

$$T_1(s) = \frac{V_c(s)}{E_i(s)} = \frac{1}{(R_1+R_2)sC + 1} \qquad (5\text{-}1)$$

or

$$T_1(s) = \frac{1}{(R_1+R_2)s\beta + 1} \qquad (5\text{-}2)$$

The parameter-plane curves for this transfer function $T_1(s)$ were obtained (Fig. 5.2), and the nonlinear relationship between β and magnitude of voltage across it, for this particular example, was superimposed on these curves, making it possible to obtain successive values of β as a function of frequency.

From the flow graph for the network, it is seen that

$$T(s) = \frac{E_o(s)}{E_i(s)} = \frac{sCR_1}{(R_2+R)sC + 1} = \frac{s\beta R_1}{(R_2+R_1)s\beta + 1} \qquad (5\text{-}3)$$

This is the principal transfer function, giving output voltage in terms of input voltage.

It is also seen that

$$|E_o| = \frac{R_1}{\left[(R_2+R_1)^2 + \left(1/\omega\beta\right)^2\right]^{1/2}} |E_i| \qquad (5\text{-}4)$$

Equation 5-4 represents the frequency response of the network, giving magnitude of output voltage in terms of frequency. For the present case, β is nonlinear, but also has been obtained as a function of frequency, from the parameter plane.

Using this result, it is possible to obtain the frequency response of the network, by hand calculation for several values of ω.

In this example, β was chosen as the following function of V_β

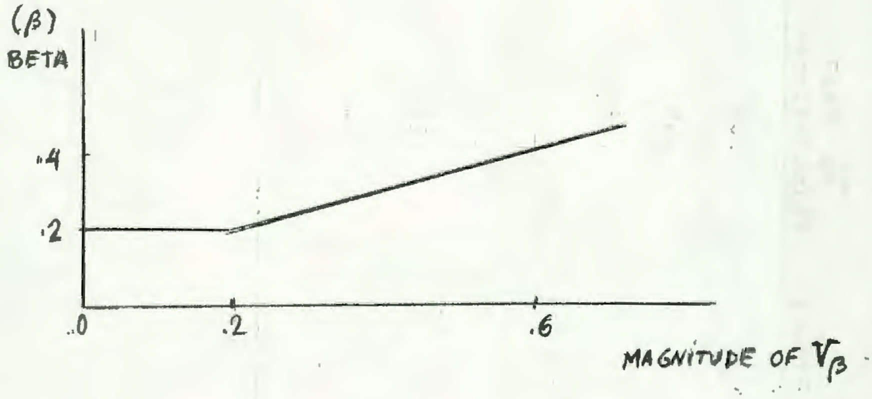

Fig. 5.4 Beta as Nonlinear Function of Magnitude

$\beta = .2$ for magnitude of $V_\beta \leq .2$

$\beta = .1 + .5 \times$ (magnitude of V_β) for magnitude of $V_\beta > .2$

and $R_2 = 1$, $R_1 = 3$ and $|E_i| = 1$.

The results obtained are summarized in the following table, and it was considered that the simulation results agree, within acceptable range, with the values from the method presented.

Results Obtained by Using Parameter Plane Method on Indirect Nonlinearity, for Frequency Response of First Order Filter

ω rad/sec	V_β Magn. (From Param Plane)	V_β Magn. (Simulation)	β From From Param 5	$\lvert E_o \rvert$ From Formula (5-4)	$\lvert E_o \rvert$ From Simulation
1.	.575	.65	.38	.63	.55
2.	.395	.46	.29	.69	.655
4.	.265	.289	.22	.725	.716
5.	.22		.22	.73	
8.	.17	.154	.2	.74	.74
10.	.12	.124	.2	.745	.744
20.	.055	.061	.2	.748	.747

6. Conclusions.

In the present work it was shown that it is possible to obtain the frequency response of networks with one nonlinear element, (whether or not it is directly across the output voltage) by a graphical method using the parameter plane concept. Also, the fact that computer programs were available made it easy to obtain the parameter plane curves, thereby avoiding the somewhat more extensive calculations involving describing-function techniques.

The method may be considered reasonably accurate, giving acceptable results accurate within the usual approximations. It was also shown that it provides a rapid way of defining the kind of nonlinear element needed to reshape the network response in a desired way, the only limitation here being the practical realization of the nonlinear element found to be required.

As areas for extension of this work it would be of interest to study the applications of the parameter-plane curves in connection with the jump resonance phenomena, for nonlinear networks, and the possibility of modifying the response by changing the nonlinearity so as to avoid three-point intersections with the frequency curves in the parameter plane. Also, the investigation of the behavior of networks and the applicability of the method for cases where the input voltage has magnitude different than unity, that is, large or small values of voltage. The usefulness of the method for cases where there is more than one nonlinear element present, and the combination of their effects for obtaining a certain response, is another subject which may prove to be of interest.

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APPENDIX I

"PARAMS" Digital Computer Program

(IBM System 360)

APPENDIX I

FORTRAN IV G LEVEL, 1, MOD 2

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                   MAIN                DATE = 68261            21/16/08

C****** PROGRAM PARAMS **********
C  THIS PROGRAM CONVERTS A GIVEN TRANSFER FUNCTION TO A SET OF FREQUENCY
CDOMAIN REPRESENTATIONS FOR ANALYSIS AND DESIGN STUDIES. THIS TRANSFER
CFUNCTION IS READ AS A RATIO OF TWO COMPLEX FREQUENCY POLYNOMIALS, WITH
CTWO VARIABLE PARAMETERS ALPHA AND BETA EMBEDDED IN THE COEFFICIENTS.
CTHE PROGRAM THEN TRANSFORMS THIS  TRANSFER FUNCTION INTO THE ANGULAR
CFREQUENCY DOMAIN, YIELDING AN EQUATION IN TERMS OF FOUR VARIABLES:
CALPHA, BETA, MAGNITUDE, AND OMEGA. SEVEN TWO-DIMENSIONAL GRAPHICAL
CREPRESENTATIONS ARE GENERATED BY FIXING ONE VARIABLE AS A CONSTANT;
CASSIGNING DESIRED CURVE VALUES TO ANOTHER; AND LETTING THE REMAINING
CTWO VARIABLES BE THE ORDINATE AND ABCISSA VALUES. A THIRD COEFFICIENT
CVARIABLE PARAMETER, GAMMA, MAY ALSO BE EMBEDDED INTO THE POLYNOMIAL.
CIN THIS CASE, THE ABOVE PROCESS IS REPEATED FOR EACH VALUE OF THE THIRD
CVARIABLE.          .....  DATA CARD INFORMATION FOLLOWS  ......
C*******************DATA CARD INFORMATION  SECTION************************
CCARD FORMAT  SYMBOL        USAGE OF SYMBOL
C  1    8I10   NRUN     NUMBER OF DESIRED RUNS. EACH MUST HAVE A COMPLETE
C                       SET OF DATA CARDS LISTED BELOW. NOT EVERY SYMBOL
C                       IS USED IN ALL CASES. LEAVE UNUSED SYMBOLS BLANK.
C                       DO NOT OMIT ANY BLANK CARDS, UNLESS SO SPECIFIED.
C                       INSERT ADDITIONAL CARDS BEHIND EACH FULL CARD.
C  2    8I10   KPARAM   NUMBER OF GRAPHICAL PRESENTATIONS TO BE PROGRAMMED
C              JPARAM   NUMERICAL TITLES (1 TO 7) OF EACH PARAM TO BE RUN;
C                       MUST AGREE IN NUMBER WITH KPARAM ABOVE.
C  3    8I10   NORN     ORDER OF NUMERATOR POLYNOMIAL (LIMITED TO 49)
C              NORD     ORDER OF DENOMINATOR POLYNOMIAL (LIMITED TO 49)
C              MODORD   Y-AXIS VARIABLE, AND CURVE VARIABLE CONTROL
C                       MODORD=1: ALPHA IS ORDINATE VARIABLE (PARAM 1-6)
C                       MODORD=2: BETA  IS ORDINATE VARIABLE (PARAM 1-6)
C                       MODORD=1: ALPHA CURVES WILL BE PLOTTED (PARAM 7)
C                       MODORD=2: BETA CURVES WILL BE PLOTTED (PARAM 7)
C              NALPHA   NUMBER OF ALPHA CURVES DESIRED (LIMITED TO 16)
C              NBETA    NUMBER OF BETA CURVES DESIRED (LIMITED TO 16)
C              NMAG     NUMBER OF MAGNITUDE CURVES DESIRED (LIMITED TO 16)
C              NOMEGA   NUMBER OF OMEGA CURVES DESIRED (LIMITED TO 16)
C              NGAMMA   POSITIVE INTEGER DENOTES NUMBER OF THIRD PARAMETER
C                       VALUES TO BE EMBEDDED INTO EACH PARAM RUN. INSERT
C                       COEFFICIENTS FOR THESE GAMMA VALUES ON SEPARATE
C                       CARDS DIRECTLY BEHIND REST OF COEFFICIENTS: SEE#19
C                       NEGATIVE INTEGER DENOTES NUMBER OF PARAM-7 VECTOR
C                       ADDITIONS FOR GENERALIZED BLOCK DIAGRAM STUDIES.
C                       THE (NEGATIVE) VALUE OF NGAMMA DETERMINES HOW MANY
C                       BODE CALCULATIONS WILL BE MADE BEFORE PLOTTING THE
C  4    8I10   IMAG     MAGNITUDE VALUE FORM CONTROL
C                       IMAG=0: ALL VALUES IN DECIBELS (PARAM 7 THIS FORM)
C                       IMAG=1 MEANS ALL VALUES IN ACTUAL MAGNITUDE
C                       IMAG=2 MEANS ALL VALUES IN MAGNITUDE SQUARED
C              IWRITE   PRINTOUT CONTROL
C                       IWRITE=-1 MEANS NO PRINTOUT
C                       IWRITE=0 MEANS ONLY INPUT DATA WILL BE PRINTED
C                       IWRITE=1 TO 900 YIELDS INPUT DATA, GRAPHICAL
C                       INFORMATION, AND COMPUTATIONAL RESULTS. THE NUMBER
C                       OF COMPUTATIONS BETWEEN EACH PRINTOUT IS DICTATED
C                       BY THE VALUE  OF IWRITE. IF IWRITE IS GREATER THAN
C                       900, ONLY INPUT DATA & GRAPH INFO. WILL BE PLOTTED
C              IGRAPH   FREQUENCY SCALING CONTROL
C                       IGRAPH=-2: NO GRAPHS WILL BE PLOTTED.
C                       IGRAPH=-1:ONLY PARAM 7 WILL BE PLOTTED ON LOG GRID
C                       IGRAPH=0: PARAMS 6&7 WILL BE PLOTTED ON LOG GRID.
C                       IGRAPH=1:PARAMS 4,6,&7 WILL BE PLOTTED ON LOG GRID
C                       IGRAPH=2: PARAMS 4&7 WILL BE PLOTTED ON LOG GRID.
C              IPHASE   PARAM 7 PHASE PLOT CONTROL
C                       IPHASE=-1 MEANS NO PHASE CURVES
C                       IPHASE=0: PHASE CURVES SUPERIMPOSED ON MAGNITUDE
C                       IPHASE=1: PHASE CURVES PLOTTED ON SEPARATE GRAPH
C              IQUAD    PARAM 7 PHASE PLOT SCALING CONTROL
C                       IQUAD=0: PHASE CURVES AUTOMATICALLY SCALED AT 45
C                       DEGREES/INCH, WITH -180 COINCIDENT WITH 0 DB MAG.
C                       IQUAD=1 TO 100: PHASE CURVES FROM 0 DEGREES TO
C                       -(IQUAD)(LX) DEGREES AT A SCALE OF IQUAD DEG/INCH
C              IPOLAR   PARAM 7 POLAR PLOT CONTROL
C                       IPOLAR=0 MEANS NO POLAR PLOT
C                       IPOLAR=1 GIVES POLAR PLOT ON SEPARATE GRAPH
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C              LX       LENGTH OF X-AXIS  (LIMITED TO 9 INCHES)
C              LY       LENGTH OF Y-AXIS  (LIMITED TO 15 INCHES)
C   5  8E10.3  CONALP   VALUE OF ALPHA WHEN USED AS A CONSTANT
C              CONBET   VALUE OF BETA WHEN USED AS A CONSTANT
C              CONMAG   MAGNITUDE VALUE WHEN USED AS A CONSTANT; SEE IMAG
C                       VECTOR RESULTANT AS ONE MAGNITUDE, AND ONE PHASE.
C                       INSERT ADDITIONAL SETS OF COEFFICIENTS AT END .
C              CONOME   VALUE OF OMEGA WHEN USED AS A CONSTANT (NOT ZERO)
C****************DATA CARD INFORMATION SECTION (CONTINUED)****************
CCARD FORMAT   SYMBOL        USAGE OF SYMBOL
C   6  8E10.3  ALPHMN   MIN. VALUE OF ALPHA WHEN USED AS AN AXIS VARIABLE
C              ALPHMX   MAX. VALUE OF ALPHA WHEN USED AS AN AXIS VARIABLE
C              BETAMN   MIN. VALUE OF BETA WHEN USED AS AN AXIS VARIABLE
C              BETAMX   MAX. VALUE OF BETA WHEN USED AS AN AXIS VARIABLE
C              XMAGMN   MIN. MAG. VALUE WHEN USED AS AXIS VAR.: SEE IMAG
C              XMAGMX   MAX. MAG. VALUE WHEN USED AS AXIS VAR.: SEE IMAG
C              OMEGMN   MIN. OMEGA VALUE WHEN USED AS AXIS VARIABLE
C              OMEGMX   MAX. OMEGA VALUE WHEN USED AS AXIS VARIABLE
C                       NOTE:IF LOG GRID IS REQUESTED,(SEE IGRAPH), OMEGMN
C                       WILL BE AUTO. CHANGED TO NEAREST POWER OF 10, AND
C                       OMEGMX CHANGED LIKEWISE. THE NUMBER OF DECADES IS
C                       AUTOMATICALLY COMPUTED FROM THESE NEW VALUES.
C   7  8E10.3  ZALPHA   DESIRED VALUES FOR ALPHA CURVES (SEE NALPHA)
C   8  8E10.3  ZBETA    DESIRED VALUES FOR BETA CURVES (SEE NBETA)
C   9  8E10.3  ZMAG     DESIRED VALUES FOR MAGNITUDE CURVES(SEE NMAG&IMAG)
C  10  8E10.3  ZOMEGA   DESIRED POSITIVE OMEGA CURVE VALUES (SEE NOMEGA)
C  11  8E10.3  HA       NUMERATOR CONSTANT COEFFICIENTS IN ASCENDING ORDER
C  12  8E10.3  HAT      NUMERATOR ALPHA COEFFICIENTS IN ASCENDING ORDER
C  13  8E10.3  HBT      NUMERATOR BETA COEFFICIENTS IN ASCENDING ORDER
C  14  8E10.3  HCT      NUM. ALPHA-BETA COEFFICIENTS IN ASCENDING ORDER
C  15  8E10.3  HD       DENOMINATOR CONST. COEFFICIENTS IN ASCENDING ORDER
C  16  8E10.3  HDT      DENOMINATOR ALPHA  COEFFICIENTS IN ASCENDING ORDER
C  17  8E10.3  HET      DENOMINATOR BETA COEFFICIENTS IN ASCENDING ORDER
C  18  8E10.3  HFT      DENOM. ALPHA-BETA COEFFICIENTS IN ASCENDING ORDER
C  * *  * * * * * * * * OMIT CARDS # 19 THRU # 27 IF NGAMMA LESS THAN ONE.
C  19  8E10.3  ZGAMMA   VALUES OF THE THIRD PARAMETER; MUST MATCH NGAMMA
C  20  8E10.3  GAMHA    NUM. GAMMA-CONST.   COEFFICIENTS IN ASCENDING ORDER
C  21  8E10.3  GAMHAT   NUM. GAMMA-ALPHA    COEFFICIENTS IN ASCENDING ORDER
C  22  8E10.3  GAMHBT   NUM. GAMMA-BETA     COEFFICIENTS IN ASCENDING ORDER
C  23  8E10.3  GAMHCT   NUM. GAMMA-ALPHA-BETA COEFFS.    IN ASCENDING ORDER
C  24  8E10.3  GAMHD    DEN. GAMMA-CONST. COEFFICIENTS IN ASCENDING ORDER
C  25  8E10.3  GAMHDT   DEN. GAMMA-ALPHA  COEFFICIENTS IN ASCENDING ORDER
C  26  8E10.3  GAMHET   DEN. GAMMA-BETA   COEFFICIENTS IN ASCENDING ORDER
C  27  8E10.3  GAMHFT   DEN. GAMMA-ALPHA-BETA COEFFS.  IN ASCENDING ORDER
C  28  6A8     ITITLE   FIRST LINE GRAPH TITLE (COLUMNS 1THRU48)
C  29  6A8     ITITLE   SECOND LINE OF GRAPH TITLE (COLUMNS 1THRU48)
C                       THE NUMBER OF TITLES FOR PARAM 7 MUST MATCH THE
C                       NUMBER OF GRAPHS REQUESTED.(SEE IPHASE & IPOLAR)
C  30  6A8     JTITLE   1ST 1/2 PHASE TITLE:OMIT UNLESS NPARAM=7&IPHASE=1
C  31  6A8     JTITLE   2ND 1/2 PHASE TITLE:OMIT UNLESS NPARAM=7&IPHASE=1
C  32  6A8     KTITLE   1ST 1/2 POLAR TITLE:OMIT UNLESS NPARAM=7&IPOLAR=1
C  33  6A8     KTITLE   2ND 1/2 POLAR TITLE:OMIT UNLESS NPARAM=7&IPOLAR=1
//PARAMS EXEC  FORTGCLG
$
 IEY013I  SYNTAX
//FORT.SYSIN DD *
C***********************************************************************
C***********************************************************************
      REAL*8ITITLE(12),JTITLE(12),KTITLE(12),JOKER(9)/1H ,6HPARAM-,7HFUR
     &THER,5HALPHA,4HBETA,5HOMEGA,8HMAGNITUD,5HGAMMA,8HSEPARATE/
      REAL DM/1H1/,LA(66)/4H 0.1,4H 0.2,4H 0.3,4H 0.4,4H 0.5,4H 0.6,4H 0
     &.7,4H 0.8,4H 0.9,4H 1.0,4H 1.0,4H 2.0,4H 3.0,4H 4.0,4H 5.0,4H 6.0,
     &4H 7.0,4H 8.0,4H 9.0,4H10.0,4H10.0,4H20.0,4H30.0,4H40.0,4H50.0,
     & 4H60.0,4H70.0,4H80.0,4H90.0,4H100.,4H100.,4H200.,4H300.,4H400.,
     &4H500.,4H600.,4H700.,4H800.,4H900.,4H1000,4H1000,4H2000,4H3000,
     &4H4000,4H5000,4H6000,4H7000,4H8000,4H9000,1H ,1H1,1H2,1H3,1H4,1H5,
     &1H6,1H7,1H8,1H9,2H10,2H11,2H12,2H13,2H14,2H15,2H16/
      DIMENSION JPARAM(8),A(50),B(50),D(50),E(50),HA(50),HAT(50),HBT(50)
     &,HCT(50),HD(50),HDT(50),HET(50),HFT(50),OLDHA(50),OLDHAT(50),OLDHB
     &T(50),OLDHCT(50),OLDHD(50),OLDHDT(50),OLDHET(50),OLDHFT(50),GAMHA(
     &50),GAMHAT(50),GAMHBT(50),GAMHCT(50),GAMHD(50),GAMHDT(50),GAMHET(5
     &0),GAMHFT(50),IC(16),ZALPHA(16),ZBETA(16),ZGAMMA(16),ZMAGSQ(16),ZO
     &MEGA(16),S(16,900),T(16,900),U(16,900),V(16,900),W(16,900),X(900),
   &Y(900)
    CALL CANCEL(2)
    EQUIVALENCE(S,T,U,V,W)
  1 FORMAT(8I10)
  2 FORMAT(10X,8I10)
  3 FORMAT(6A8)
  4 FORMAT(10X,6A8)
  5 FORMAT(   8E10.3)
  6 FORMAT(10X,1P10E12.3)
C*************************INPUT DATA READ IN ****************************
    READ(5,1)NRUN
    DO 1000 IRUN=1,NRUN
    READ(5,1) KPARAM,(JPARAM(I),I=1,KPARAM)
    READ(5,1)NORN,NORD,MODORD,NALPHA,NBETA,NMAG,NOMEGA,NGAMMA
    READ(5,1) IMAG ,IWRITE ,IGRAPH,IPHASE,IQUAD,IPOLAP,LX,LY
    READ(5,5)CONALP,CONBET,CONMAG,CONOME
    READ(5,5)ALPHMN,ALPHMX,BETAMN,BETAMX,XMAGMN,XMAGMX,OMEGMN,OMEGMX
    READ(5,5) (ZALPHA(I),I=1,NALPHA)
    READ(5,5) (ZBETA(I),I=1,NBETA)
    READ(5,5) (ZMAGSQ(I),I=1,NMAG)
    READ(5,5) (ZOMEGA(I),I=1,NOMEGA)
    LOE=NORN+1
    MOE=NORD+1
    READ(5,5) (HA (I), I=1,LOE)
    READ(5,5) (HAT(I), I=1,LOE)
    READ(5,5) (HBT(I), I=1,LOE)
    READ(5,5) (HCT(I), I=1,LOE)
    READ(5,5) (HD (I), I=1,MOE)
    READ(5,5) (HDT(I), I=1,MOE)
    READ(5,5) (HET(I), I=1,MOE)
    READ(5,5) (HFT(I), I=1,MOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (ZGAMMA(I),I=1,NGAMMA)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHA (I),I=1,LOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHAT(I),I=1,LOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHBT(I),I=1,LOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHCT(I),I=1,LOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHD (I),I=1,MOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHDT(I),I=1,MOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHET(I),I=1,MOE)
    IF((NGAMMA).GE.(1)) READ(5,5) (GAMHFT(I),I=1,MOE)
    IF((IWRITE).LT.(0)) GO TO 24
C**************************INPUT DATA PRINT OUT SECTION************
    WRITE(6,7) IRUN,NORN,NORD,KPARAM,(JOKER(2),JPARAM(I),I=1,KPARAM)
  7 FORMAT(1H1,10X,'*****  THE INPUT DATA FOR RUN',I2,' IS  *****',//,
   &10X,'ORDER OF NUMERATOR:',I2,//,10X,'ORDER OF DENOMINATOR:',I2,//,
   &10X,'THE FOLLOWING',I2,' GRAPHICAL CONFIGURATIONS WILL BE COMPUTED
   &:',//,20X,8(A8,I1,3X),/)
    IF((NGAMMA).GE.(1)) WRITE(6,8) NGAMMA,(ZGAMMA(I),I=1,NGAMMA)
  8 FORMAT(10X,I2,' GAMMA, OR THIRD VAR. PARAMETER COEFFICIENTS WILL B
   &E USED.',//,10X,'THE GAMMA VALUES ARE:',1P8E12.3,/,10X,1P8E12.3,/)
    WRITE(6,10)
 10 FORMAT(/,10X,'THE COEFFICIENTS FOR THE NUMERATOR ARE:',/)
    DO 11 I=1,LOE
    J=I-1
    IF(NGAMMA .LE.0) WRITE(6,12) HA(I),HAT(I),HBT(I),HCT(I),J
 12 FORMAT(20X,'(',1PE10.3,'+',1PE10.3,'*ALPHA + ' ,1PE10.3,'*BETA + '
   &,1PE10.3,'*ALPHA*BETA ) * S**(',I2,')',/)
    IF(NGAMMA .GT.0) WRITE(6, 9) HA(I),GAMHA(I),HAT(I),GAMHAT(I),HBT(I
   &),GAMHBT(I),HCT(I),GAMHCT(I),J
  9 FORMAT(15X,'((',1PE10.3,'+',1PE10.3,'*GAMMA)+(',1PE10.3,'+',1PE10.
   &3,'*GAMMA)*ALPHA ....',//,20X,'+(',1PE10.3,'+',1PE10.3,'*GAMMA)*BE
   &TA+(',1PE10.3,'+',1PE10.3,'*GAMMA)*ALPHA*BETA)**(',I2,')',/)
 11 CONTINUE
    WRITE(6,13)
 13 FORMAT(/10X,'THE COEFFICIENTS FOR THE DENOMINATOR ARE:',/)
    DO 14 I=1,MOE
    J=I-1
    IF(NGAMMA .LE.0) WRITE(6,12) HD(I),HDT(I),HET(I),HFT(I),J
    IF(NGAMMA .GT.0) WRITE(6, 9) HD(I),GAMHD(I),HDT(I),GAMHDT(I),HET(I
   &),GAMHET(I),HFT(I),GAMHFT(I),J
 14 CONTINUE
    WRITE(6,15)
 15 FORMAT(15X,'  NORN       NORD       MODORD     NALPHA      NBETA      NMA
     &      NOMEGA   NGAMMA ',/)
      WRITE(6,2 ) NORN,NORD,MODORD,NALPHA,NBETA,NMAG,NOMEGA,NGAMMA
      WRITE(6,16)
   16 FORMAT(/,17X,'IMAG       IWRITE    IGRAPH     IPHASE      IQUAD     IPO
     &LAR      LXAXIS     LYAXIS   ',/)
      WRITE(6,2)  IMAG ,IWRITE,IGRAPH,IPHASE,IQUAD,IPOLAR,LX,LY
      WRITE(6,17)
   17 FORMAT(/,12X,' CONALPHA     CONBETA        CONMAG        CONOMEGA   ',/)
      WRITE(6,6 )CONALP,CONBET,CONMAG,CONOME
      WRITE(6,18)
   18 FORMAT(/,12X,' ALPHMIN      ALPHMAX      BETAMIN         BETAMAX        XMAG
     &MIN      XMAGMAX        OMEGAMIN        OMEGAMAX   ',/)
      WRITE(6,6)ALPHMN,ALPHMX,BETAMN,BETAMX,XMAGMN,XMAGMX,OMEGMN,OMEGMX
      WRITE(6,19) JOKER(4),(ZALPHA(I),I=1,NALPHA)
      WRITE(6,19) JOKER(5),(ZBETA (I),I=1,NBETA )
      WRITE(6,19) JOKER(7),(ZMAGSQ(I),I=1,NMAG)
      WRITE(6,19) JOKER(6),(ZOMEGA(I),I=1,NOMEGA)
   19 FORMAT(/,10X,A8,'CURVE VALUES:',1P8E12.3,/31X,1P8E12.3)
      IF(IWRITE) 20,20,22
   20 WRITE(6,21)
   21 FORMAT(/,10X,'THERE WILL BE NO PRINTOUT OF COMPUTED RESULTS')
      GO TO 24
   22 WRITE(6,23)IWRITE
   23 FORMAT(/,10X,'COMPUTED RESULTS WILL BE PRINTED EVERY',I3,' STEPS')
C*****************INITIALIZING COMPUTATIONAL SETTINGS*****************
   24 IF(MODORD.GE.2) GO TO  25
      DUMMY1=BETAMN
      DUMMY2=BETAMX
      BETAMN=ALPHMN
      BETAMX=ALPHMX
      ALPHMN=DUMMY1
      ALPHMX=DUMMY2
   25 DO 1000 IPARAM=1,KPARAM
      NPARAM=JPARAM(IPARAM)
      MGAMMA=NGAMMA+1
      DO 1000 IGAMMA=1,MGAMMA
      GAMMA=ZGAMMA(IGAMMA)
      IF(NGAMMA.GE.1) GO TO 517
   26 XS=(ALPHMX-ALPHMN)/LX
      IF((ABS(XS)).LE.(1.0E-10)) XS=1.0E-10
      YS=(BETAMX-BETAMN)/LY
      IF((ABS(YS)).LE.(1.0E-10)) YS=1.0E-10
      IX=-BETAMN/YS
      IY=-ALPHMN/XS
      MOD=1
      JCURVE=0
      IPAR7=1
      READ(5,3)(ITITLE(I),I=1,12)
      IF(NPARAM.NE.7)GO TO 34
      IF(IMAG-1)27,28,29
   27 DBMAX=XMAGMX
      DBMIN=XMAGMN
      GO TO 30
   28 DBMAX=20*ALOG10(XMAGMX)
      DBMIN=20*ALOG10(XMAGMN)
      GO TO 30
   29 DBMAX=10*ALOG10(XMAGMX)
      DBMIN=10*ALOG10(XMAGMN)
   30 XS=(DBMAX-DBMIN)/LX
      IY=DBMAX/XS
      DO 31 I=1,16
      S(I,1)=0.0
      T(I,1)=0.0
      U(I,1)=0.0
      V(I,1)=0.0
   31 W(I,1)=0.0
      IF(IPHASE.EQ.0) GO TO 32
      READ(5,3)(JTITLE(I),I=1,12)
   32 IF((IPOLAR).LE.(0)) GO TO 33
      READ(5,3)(KTITLE(I),I=1,12)
   33 IF(MODORD-2)45,44,44
   34 GO TO (35,40,41,46,47,51,59,59),NPARAM
   35 NLIMIT=NOMEGA
   36 IF(IMAG-1)37,38,39
   37 DUMMY1=10.0**(CONMAG/10.0)
      IF(NPARAM-1)59,59,43
   38 DUMMY1=CONMAG*CONMAG
      IF(NPARAM-1)59,59,43
   39 DUMMY1=CONMAG
      IF(NPARAM-1)59,59,43
   40 NLIMIT=NMAG
   41 OMEGA=CONOME
      IF(NPARAM-2)59,59,42
   42 XS=(XMAGMX-XMAGMN)/LX
      IY=-XMAGMN/XS
   43 IF(MODORD-2)44,45,45
   44 NLIMIT=NBETA
      IF(NPARAM-6)59,53,55
   45 NLIMIT=NALPHA
      IF(NPARAM-6)59,53,55
   46 NLIMIT=NMAG
      XS=(OMEGMX-OMEGMN)/LX
      IY=-OMEGMN/XS
   47 IF(MODORD-2)48,49,49
   48 CONST=CONBET
      IF(NPARAM-4)52,52,50
   49 CONST=CONALP
      IF(NPARAM-4)52,52,50
   50 XS=(XMAGMX-XMAGMN)/LX
      IY=-XMAGMN/XS
      NLIMIT=NOMEGA
      GO TO 59
   51 XS=(OMEGMX-OMEGMN)/LX
      IY=-OMEGMN/XS
      GO TO 36
   52 IF(IGRAPH)59,59,54
   53 IF((IGRAPH.LT.0).OR.(IGRAPH.GT.1)) GO TO 59
   54 IY=LX-IX
   55 IF(IGRAPH.LE.-2) GO TO 59
C******************LOG GRID GRAPHICAL CONSTRUCTION*********************
      IF(OMEGMN.LT.1000.)YLOGMN=100.
      IF(OMEGMN.LT.100. )YLOGMN=10.
      IF(OMEGMN.LT.10.  )YLOGMN=1.
      IF(OMEGMN.LT.1.   )YLOGMN=0.1
      IF(OMEGMX.GT.1.0 )YLOGMX=10.0
      IF(OMEGMX.GT.10.0)YLOGMX=100.0
      IF(OMEGMX.GT.100.)YLOGMX=1000.0
      IF(OMEGMX.GT.1000.)YLOGMX=10000.0
      DUMMY3= YLOGMX/YLOGMN
      NUMDEC=ALOG10(DUMMY3)
      IX=0
      DUMMY4=NUMDEC
      DUMMY5=LY
      YS=DUMMY4/DUMMY5
      IFINAL=LX+1
      JFINAL=LY+1
      DO 57  IA=1,IFINAL
      DO 56  JA=1,JFINAL
      X(JA)=XS*(IA-1-IY)
   56 Y(JA)=YS*(JA-1)
      CALL DRAW(JA,X,Y,MOD,0,LA(50),ITITLE,XS,YS ,0,IY,2,2,LX,LY,0,LAST)
   57 MOD=2
      DO 58 IB=1,NUMDEC
      DO 58 JB=1,10
      J=ALOG10(YLOGMN)*10.+10.+(IB-1)*10.+JB
      YLOG=JB
      DO 1058 KB=1,IFINAL
      X(KB)=XS*(KB-1-IY)
 1058 Y(KB)=ALOG10(YLOG)+IB-1
   58 CALL DRAW(KB,X,Y,MOD,0,LA(J),ITITLE,XS,YS ,0,IY,2,2,LX,LY,0,LAST)
      IF((IPAR7).NE.(1)) GO TO 532
   59 IF(IWRITE.LE.0) GO TO 200
C*****************GRAPHICAL  INFORMATION PRINTOUT SECTION**************
      WRITE(6,60) IRUN, NPARAM
   60 FORMAT(1H1,10X,'**********THE PRELIMINARY DATA FOR RUN NUMBER',I2,
     &', PARAMETER NUMBER',I2,' IS   **********',///)
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      IF(NGAMMA.GE.1) WRITE (6,61) ZGAMMA(IGAMMA)
   61 FORMAT(10X,'THE FOLLOWING CALCULATIONS WILL BE BASED ON THE THIRD
     &VARIABLE PARAMETER VALUE , GAMMA=',1PE12.5,//)
      WRITE (6,62) (ITITLE(I),I=1,12)
   62 FORMAT(10X,'THE GRAPH WILL BE TITLED:',//,10X,6A8,//,10X,6A8,/)
      IF(NPARAM.NE.7) GO TO 80
      WRITE(6,83)
      WRITE(6,   63)DBMIN,DBMAX,XS
   63 FORMAT(10X,'MAGNITUDE, THE DEPENDENT VARIABLE, WILL BE PLOTTED ON
     &THE ORDINATE FROM',F10.4,' TO',F10.4,' AT',F10.4,' DB/DIVISION',/)
      IF(IPHASE) 73,64,66
   64 WRITE(6,65)
   65 FORMAT(10X,'PHASE CURVES WILL BE PLOTTED ON MAGNITUDE GRAPH',/)
      GO TO 68
   66 WRITE(6,67)
   67 FORMAT(10X,'PHASE CURVES WILL BE PLOTTED ON SEPARATE GRAPH';/)
   68 IF(IQUAD.GT.0) GO TO 70
      WRITE(6,69)
   69 FORMAT(10X,'AUTOMATICALLY SCALED AT 45DEG/IN,-180 ON 0DB MAG.',/)
      GO TO 72
   70 WRITE(6,71) IQUAD
   71 FORMAT(10X,'WITH A SCALE OF',I3,' DEG/IN, STARTING AT 0 DEG.',/)
   72 WRITE(6,62) (JTITLE(I),I=1,12)
   73 IF(IPOLAR.LE.0) GO TO 75
      WRITE(6,74) XS
   74 FORMAT(10X,'A POLAR PLOT OF MAGNITUDE VS. PHASE WILL BE PLOTTED, W
     &ITH MAGNITUDE SCALED AT',F10.5,' DECIBELS  PER HALF INCH',/)
      WRITE(6,62) (KTITLE(I),I=1,12)
   75 IF(MODORD-2)127,121,121
   76 FORMAT(10X,A8,', THE  DEPENDENT VARIABLE, WILL BE PLOTTED ON THE
     &ORDINATE FROM',1PE10.3,' TO',1PE10.3,' WITH A SCALE OF',1PE10.3,/)
   77 FORMAT(10X,A8,', THE INDEPENDENT VARIABLE, WILL BE PLOTTED ON THE
     &ABCISSA, FROM',1PE10.3,' TO',1PE10.3,' WITH A SCALE OF',1PE10.3,/)
   78 FORMAT(10X,A8,' WILL BE HELD CONSTANT AT THE VALUE OF',1PE12.5,/)
   79 FORMAT(10X,A8,' WILL BE GRAPHED AS ',I3,' CURVES, CONSISTING OF TH
     &E FOLLOWING VALUES:',/,16(20X,'CURVE',I3,' = ',1PE12.5,/))
   80 IF(IMAG.EQ.0) WRITE(6,83)
      IF(IMAG.EQ.1) WRITE(6,84)
      IF(IMAG.EQ.2) WRITE(6,85)
   81 IF(MODORD-2) 82,  94,1000
   82 WRITE(6,76) JOKER(4),BETAMN,BETAMX, YS
   83 FORMAT(10X,'ALL MAGNITUDE COMPUTATIONS WILL BE IN DECIBELS',/)
   84 FORMAT(10X,'ALL MAGNITUDE COMPUTATIONS ARE ACTUAL MAGNITUDE',/)
   85 FORMAT(10X,'ALL MAGNITUDE COMPUTATIONS ARE MAGNITUDE SQUARED',/)
      GO TO (86,86,121,130,130,121,200,200),NPARAM
   86 WRITE(6,77) JOKER(5),ALPHMN,ALPHMX,XS
      IF(NPARAM-1) 88,88,99
   88 WRITE(6,78) JOKER(7),CONMAG
   90 WRITE(6,79)JOKER(6),NOMEGA,(I,ZOMEGA(I),I=1,NOMEGA)
      IF(NPARAM-5)200,125,200
   94 WRITE(6,76) JOKER(5),BETAMN,BETAMX, YS
   96 GO TO(97,97,127,111,111,127,200,200),NPARAM
   97 WRITE(6,77) JOKER(4),ALPHMN,ALPHMX,XS
      IF(NPARAM-1)88,88,99
   99 WRITE(6,78) JOKER(6),CONOME
  101 WRITE(6,79)JOKER(7),NMAG,(I,ZMAGSQ(I),I=1,NMAG)
      IF(NPARAM-4)200,139,200
  111 WRITE(6,78) JOKER(4),CONALP
  113 WRITE(6,114)
  114 FORMAT(10X,'THE COMBINED COEFFICIENTS OF THE NUMERATOR ARE',/)
  115 DO 116 I=1,LOE
      A(I)=HA(I)+HAT(I)*CONST
      B(I)=HBT(I)+HCT(I)*CONST
      KA=I-1
  116 WRITE(6,117) A(I),B(I),KA
  117 FORMAT(20X,1H(,E10.4,3H + , E10.4,16H * BETA ) * S**(,I2,1H)/)
      WRITE(6,136)
      DO 119 I=1,MOE
      D(I)=HD(I)+HDT(I)*CONST
      E(I)=HET(I)+HFT(I)*CONST
      KA=I-1
  119 WRITE(6,117) D(I),E(I),KA
  120 GO TO (200,200,200,101, 90,200,139,200),NPARAM
```

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 121 WRITE(6,79)JOKFR(5),NBETA,(I,ZBETA(I),I=1,NBETA)
     IF(NPARAM-6)124,138,111
 124 WRITE(6,78) JOKER(6),CONOME
 125 WRITE(6,77) JOKER(7),XMAGMN,XMAGMX,XS
     GO TO 200
 127 WRITE(6,79)JOKER(4),NALPHA,(I,ZALPHA(I),I=1,NALPHA)
     IF(NPARAM-6)124,138,130
 130 WRITE(6,78) JOKER(5),CONBET
 131 FORMAT(10X,'BETA  WILL BE HELD CONSTANT AT THE  VALUE OF',F10.4,/)
 132 WRITE(6,114)
     DO 134 I=1,LOE
     A(I)=HA(I)+HBT(I)*CONST
     B(I)=HAT(I)+HCT(I)*CONST
     KA=I-1
 134 WRITE(6,135)A(I),B(I),KA
 135 FORMAT(20X,1H(,E10.4,3H + ,E10.4,17H * ALPHA ) * S**(,I2,1H)/)
     WRITE(6,136)
 136 FORMAT(10X,'THE COMBINED COEFFICIENTS OF THE DENOMINATOR ARE-',/)
     DO 137 I=1,MOE
     D(I)=HD(I)+HET(I)*CONST
     E(I)=HDT(I)+HFT(I)*CONST
     KA=I-1
 137 WRITE(6,135) D(I),E(I),KA
     GO TO 120
 138 WRITE(6,78) JOKER(7),CONMAG
 139 WRITE(6,140)
 140 FORMAT(10X,'OMEGA,THE INDEPENDENT VARIABLE,WILL BE PLOTTED ON THE
    &ABCISSA',/)
     IF(NPARAM-6)141,143,144
 141 IF(IGRAPH)142,142,144
 142 WRITE(6,146) OMEGMN,OMEGMX,XS
     GO TO 200
 143 IF((IGRAPH.LT.0).OR.(IGRAPH.GT.1)) GO TO 142
 144 WRITE(6,145)NUMDEC,YLOGMN
 145 FORMAT(10X,'WITH A SPAN OF',I2,' DECADES,STARTING AT',F10.4,//,30X
    &,'*****NOTE*****',//,10X,'FOR THIS LOG PLOT, IT WILL BE NECESSARY
    &TO SHIFT THE ORIGIN TO THE LOWER RIGHT HAND CORNER,',//,10X,'WITH
    &THE ABCISSA RUNNING UP THE RIGHT HAND EDGE, AND THE ORDINATE INCRE
    &ASING TOWARDS THE LEFT ALONG THE BOTTOM'//)
 146 FORMAT(10X,'FROM THE INITIAL VALUE OF',1PE10.3,'TO THE FINAL VALUE
    & OF',1PE10.3,' WITH A SCALE OF ',1PE10.3,' RADIANS PER INCH',/)
C*******************MAIN COMPUTATIONAL SECTION DO LOOPS****************
 200 IF((IWRITE.LT.1).OR.(IWRITE.GT.900)) GO TO 203
     WRITE(6, 201)IRUN,NPARAM,IWRITE
 201 FORMAT(1H1,10X,'*********THE OUTPUT DATA FOR RUN NUMBER',I2,', PAR
    &AMETER NUMBER',I2,' IS**********',////,10X,I2,' COMPUTATIONS WILL
    &BE PERFORMED BETWEEN EACH PRINTOUT',///)
     IF(NGAMMA.GT.0) WRITE(6,202) ZGAMMA(IGAMMA)
 202 FORMAT(10X,'THE VALUE OF GAMMA, THE THIRD VARIABLE IS:',1PE10.3,/)
 203 DO 520 LOM=1,NLIMIT
     JCURVE=0
     DO 519 ICOEF=1,3,2
     ZSIGN=ICOEF-2
     IF((IWRITE.LT.1).OR.(IWRITE.GT.900)) GO TO 208
     WRITE(6,205 )LOM
 205 FORMAT(//,10X,'COMPUTATIONAL RESULTS FOR CURVE NUMBER',I3)
     IF (NPARAM-7)206,208,208
 206 WRITE(6,207 )ZSIGN
 207 FORMAT(1H+,55X,' USING A QUADRATIC FORMULA COEFFICIENT OF',F4.1,/)
 208 IP=0
     YMAGPK=0.0
     OMEGPK=0.0
     DO 518 INCRMT=1,900
     GO TO (209,216,253,216,212,254,257,1000),NPARAM
 209 OMEGA=ZOMEGA(LOM)
 211 CONST=ALPHMN+(INCRMT-1)*(ALPHMX-ALPHMN)/899.0
 212 IF(MODORD-2)260,213,213
 213 DO 214  I=1,LOE
     A(I)=HA(I)+HAT(I)*CONST
 214 B(I)=HBT(I)+HCT(I)*CONST
     DO 215 I =1,MOE
     D(I)=HD(I)+HDT(I)*CONST
 215 E(I)=HET(I)+HFT(I)*CONST
```

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      GO TO 263
  216 IF(IMAG-1)217,218,219
  217 DUMMY1=10.0**(ZMAGSQ(LOM)/10.0)
      GO TO 220
  218 DUMMY1=ZMAGSQ(LOM)*ZMAGSQ(LOM)
      GO TO 220
  219 DUMMY1=ZMAGSQ(LOM)
  220 IF(NPARAM-2)211,211,212
  253 OMEGA=CONOME
  254 IF(MODORD-2)255,256,1000
  255 CONST=ZBETA(LOM)
      GO TO 260
  256 CONST=ZALPHA(LOM)
      GO TO 213
  257 IF(MODORD-2)259,258,258
  258 BETA=ZBETA(LOM)
      CONST=CONALP
      GO TO 213
  259 BETA=ZALPHA(LOM)
      CONST=CONBET
  260 DO 261  I=1,LOE
      A(I)=HA(I)+HBT(I)*CONST
  261 B(I)=HAT(I)+HCT(I)*CONST
      DO 262  I=1,MOF
      D(I)=HD(I)+HET(I)*CONST
  262 E(I)=HDT(I)+HFT(I)*CONST
  263 GO TO (350,350,275, 290,264 ,291,294,1000),NPARAM
  264 OMEGA=ZOMEGA(LOM)
  275 ZMAG=XMAGMN+(INCRMT-1)*(XMAGMX-XMAGMN)/899.0
      IF(IMAG-1)276,277,278
  276 DUMMY1=10.0**(ZMAG/10.0)
      GO TO 350
  277 DUMMY1=ZMAG*ZMAG
      GO TO 350
  278 DUMMY1=ZMAG
      GO TO 350
  290 IF(IGRAPH)292,292,294
  291 IF((IGRAPH.GE.0).AND.(IGRAPH.LE.1)) GO TO 294
  292 OMEGA=OMEGMN+INCRMT*(OMEGMX-OMEGMN)/900.0
      GO TO 350
  294 WINC=1.0+(INCRMT-1)*NUMDEC/899.0
      OMEGA=(YLOGMN*10.0**WINC)/10.0
C***************NUMERATOR COEFFICIENT CALCULATIONS************************
  350 SNB2=0.0
      SNB1=0.0
      SNB0=0.0
      SUMN=0.0
      NDOUN=2*NORN
      DO 373 ILOOP=1,4
      DO 373 NP=2,LOE
      DO 373 MQ=1,NORN
      MP=MQ-1
      NQ=NP-1
      IF(((NP+MQ).GT.NDOUN).AND.(NORN.NE.1)) GO TO 373
  361 IF((MP+NQ)-NORN)362,362,373
  362 IF(NP-MP)373,373,363
  363 IF(MP)364,364,366
  364 C=1.0
      GO TO 367
  366 C=2.0
  367 GO TO (368,369,370,371),ILOOP
  368 CSNB2 = (C*B(NP+MP)*B(NP-MP))*OMEGA**(2*NQ)*(-1.0)**(MQ+1)
      SNB2 = SNB2 + CSNB2
      GO TO 373
  369 CSNB1 = (C*A(NP+MP)*B(NP-MP)+C*A(NP-MP)*B(NP+MP))*OMEGA**(2*NQ)*(-
     11.0)**(MQ+1)
      SNB1 = SNB1 + CSNB1
      GO TO 373
  370 CSNB0 = (C*A(NP+MP)*A(NP-MP))*OMEGA**(2*NQ)*(-1.0)**(MQ+1)
      SNB0 = SNB0 + CSNB0
      GO TO 373
  371 COEFN = (C*A(NP+MP)*A(NP-MP)+C*A(NP+MP)*B(NP-MP)*BETA+C*A(NP-MP)*B
     1(NP+MP)*BETA+C*B(NP+MP)*B(NP-MP)*BETA*BETA)*OMEGA**(2*NQ)*(-1.0)**
     2(MQ+1)
      SUMN = SUMN + COEFN
  373 CONTINUE
      SNB2 = SNB2 + B(1)*B(1)
      SNB1 = SNB1 + 2.0*A(1)*B(1)
      SNBO=SNBO+A(1)*A(1)
      SUMN = SUMN + A(1)*A(1)+2.0*A(1)*B(1)*BETA+B(1)*B(1)*BETA*BETA
C************DENOMINATOR COEFFICIFNT CALCULATIONS*************************
      SDB2=0.0
      SDB1=0.
      SDBO=0.
      SUMD=0.
      NDOUD=2*NORD
      DO 385 ILOOP=1,4
      DO 385 NP=2,MOE
      DO 385 MQ=1,NORD
      MP=MQ-1
      NQ=NP-1
      IF(((NP+MQ).GT.NDOUD).AND.(NORD.NE.1))  GO TO 385
  375 IF((MP+NQ)-NORD)376,376,385
  376 IF(NP-MP)385,385,377
  377 IF(MP)378,378,379
  378 C=1.0
      GO TO 380
  379 C=2.0
  380 GO TO (381,382,383,384),ILOOP
  381 CSDB2 =  C*E(NP+MP)*E(NP-MP)*OMEGA**(2*NQ)*(-1.0)**(MQ+1)
      SDB2 = SDB2 + CSDB2
      GO TO 385
  382 CSDB1 = (C*D(NP+MP)*E(NP-MP)+C*D(NP-MP)*E(NP+MP))*OMEGA**(2*NQ)*(-
     11.0)**(MQ+1)
      SDB1 = SDB1 + CSDB1
      GO TO 385
  383 CSDBO = (C*D(NP+MP)*D(NP-MP))*OMEGA**(2*NQ)*(-1.0)**(MO+1)
      SDBO = SDBO + CSDBO
      GO TO 385
  384 COEFD = (C*D(NP+MP)*D(NP-MP)+C*D(NP+MP)*E(NP-MP)*BETA+C*D(NP-MP)*E
     1(NP+MP)*BETA+C*E(NP+MP)*E(NP-MP)*BETA*BETA)*OMEGA**(2*NQ)*(-1.0)**
     2(MQ+1)
      SUMD = SUMD + COEFD
  385 CONTINUE
      SUMD = SUMD + D(1)*D(1)+2.0*D(1)*E(1)*BETA+E(1)*E(1)*BETA*BETA
      SDB2 = SDB2 + E(1)*E(1)
      SDB1 = SDB1 + 2.0*D(1)*E(1)
      SDBO = SDBO + D(1)*D(1)
      IF(NPARAM-7)413, 386,1000
C***********************PARAM 7 PHASE COMPUTATIONAL SECTION************
  386 TOE=LOE/2.0
      PNEVEN=0.
      PDEVEN=0.
      PNODD=0.
      PDODD=0.
      JOE=LOE/2
      IF(JOE-TOE)387,388,388
  387 JON=(LOE+1)/2
      MON=JON
      GO TO 389
  388 JON=(LOE+2)/2
      MON=JON-1
      IF(NORN-1)393,389,389
  389 DO 390 I=2,JON
  390 PNODD=PNODD+(A(2*I-2)+B(2*I-2)*BETA)*OMEGA**(2*I-3)*(-1.0)**(I)
      IF(NORN-1)393,393,391
  391 DO 392 I=2,MON
  392 PNEVEN=PNEVEN+(A(2*I-1)+B(2*I-1)*BETA)*OMEGA**(2*I-2)*(-1.)**(I-1)
  393 PNEVEN=PNEVEN+A(1)+B(1)*BETA
      TOE=MOE/2.0
      JOE=MOE/2
      IF(JOE-TOE)394,395,395
  394 JON=(MOE+1)/2
      MON=JON
      GO TO 396
  395 JON=(MOE+2)/2
```

```
      MON=JON-1
      IF(NORD-1)400,396,396
  396 DO 397 I=2,JON
  397 PDODD=PDODD+(D(2*I-2)+E(2*I-2)*BETA)*OMEGA**(2*I-3)*(-1.0)**(I)
      IF(NORD-1)400,400,398
  398 DO 399 I=2,MON
  399 PDEVEN=PDEVEN+(D(2*I-1)+E(2*I-1)*BETA)*OMEGA**(2*I-2)*(-1.)**(I-1)
  400 PDEVEN=PDEVEN+D(1)+F(1)*BETA
      TANGIM=PDEVEN*PNODD-PNEVEN*PDODD
      TANGRE=PNEVEN*PDEVEN+PNODD*PDODD
      TANG=TANGIM/TANGRE
      RAD=ATAN(TANG)
      IF((TANGRE.GT.0.0).AND.(TANGIM.GT.0.0)) JQUAD=1
      IF((TANGRE.GT.0.0).AND.(TANGIM.LT.0.0)) JQUAD=-1
      IF(TANGRE.LT.0.0) RAD=JQUAD*(3.141593+JQUAD*RAD)
  402 YMAGSQ=ABS(SUMN/SUMD)
      YMAG=SQRT(YMAGSQ)
      YMAGDB=20.0*.4342945*ALOG(YMAG)
      YMAGAB=ABS(YMAGDB)
      IF(YMAGPK-YMAGDB)403,404,404
  403 YMAGPK=YMAGDB
      OMEGPK=OMEGA
  404 IF(DBMAX-YMAGDB)405,406,406
  405 YMAGDB=DBMAX
  406 IF(YMAGDB-DBMIN)407,408,408
  407 YMAGDB=DBMIN
  408 IF((XS*LX )-YMAGAB)409,410,410
  409 YMAGAB=LX*XS
  410 GO TO 426
C*****************QUADRATIC FORMULA SOLN. OF DEPENDENT VARIABLE, PARAM1-6
  413 ACO=DUMMY1*SDB2-SNB2
  416 BCO=DUMMY1*SDB1-SNB1
      CCO=DUMMY1*SDB0-SNB0
      IF(ABS(ACO).LT.1.0E-35) GO TO 425
      DPP=BCO*BCO-4.0*ACO*CCO
      IF(DPP.LT.0.0) GO TO 425
      DSQR=ZSIGN*SQRT(DPP)
      BETA=(DSQR-BCO)/(2.0*ACO)
      IF(BETA-BETAMN)425,426.424
  424 IF(BETA-BETAMX)426,426,425
  425 IF(IP-1)500,505,507
  426 IF((IWRITE.LT.1).OR.(IWRITE.GT.900)) GO TO 450
C*******************COMPUTED DATA PRINTOUT SECTION*********************
      ISTEP=ISTEP+1
      IF(IP)428,428,427
  427 IF(ISTEP-IWRITE)450,430,430
  428 WRITE(6,429)LOM
  429 FORMAT(/,10X,'    ALPHA         BETA      MAGNITUDE          OMEGA
     & TANGENT  :  CURVE NUMBER',I2,/)
  430 IF(MODORD.EQ.2) GO TO 431
      GO TO (433,435,436,437,439,441,443,1000),NPARAM
  431 GO TO (432,434,445,438,440,442,444,1000),NPARAM
  432 WRITE(6,6)    CONST,BETA,CONMAG,OMEGA
      GO TO 448
  433 WRITE(6,6)    BETA,CONST,CONMAG,OMEGA
      GO TO 448
  434 WRITE(6,6)    CONST,BETA,ZMAGSQ(LOM),OMEGA
      GO TO 448
  435 WRITE(6,6)    BETA,CONST,ZMAGSQ(LOM),OMEGA
      GO TO 448
  436 WRITE(6,6)    BETA,CONST,ZMAG,OMEGA
      GO TO 448
  437 WRITE(6,6)    BETA,CONBET,ZMAGSQ(LOM),OMEGA
      GO TO 448
  438 WRITE(6,6)    CONALP,BETA,ZMAGSQ(LOM),OMEGA
      GO TO 448
  439 WRITE(6,6)    BETA,CONBET,ZMAG,OMEGA
      GO TO 448
  440 WRITE(6,6)    CONALP,BETA,ZMAG,OMEGA
      GO TO 448
  441 WRITE(6,6)    BETA,CONST,CONMAG,OMEGA
      GO TO 448
  442 WRITE(6,6)    CONST,BETA,CONMAG,OMEGA
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      GO TO 448
  443 WRITE(6,6)  ZALPHA(LOM),CONBET,YMAGDB,OMEGA,TANG
      GO TO 448
  444 WRITE(6,6)  CONALP,ZBETA(LOM),YMAGDB,OMEGA,TANG
      GO TO 448
  445 WRITE(6,6)   CONST,BETA,ZMAG,OMEGA
  448 ISTEP=0
C*******************GRAPHICAL ARRAY STORAGE SECTION*********************
  450 IP=IP+1
      Y(IP)= BETA
  452 GO TO (453,453,460,470,460,470,475 ,1000),NPARAM
  453 X(IP)= CONST
      GO TO 500
  460 X(IP)=ZMAG
      GO TO 500
  470 X(IP)=OMEGA
      IF(NPARAM-6)471,472,475
  471 IF(IGRAPH)500,500,474
  472 IF((IGRAPH.LT.0).OR.(IGRAPH.GT.1)) GO TO 500
  474 X(IP)=LX-BETA
      GO TO 479
  475 X(IP)=-YMAGDB
      U(LOM,IP)=U(LOM,IP)+YMAG
      V(LOM,IP)=(ALOG10(OMEGA/YLOGMN)*LY/NUMDEC)*YS
      S(LOM,IP)=(YMAGAB*COS(RAD))/XS
      T(LOM,IP)=(YMAGAB*SIN(RAD))/XS
      IC(LOM)=IP
      IF(IQUAD.LE.0) GO TO 476
      W(LOM,IP)=  -(IY+RAD*57.29256/IQUAD)*XS
      GO TO 477
  476 W(LOM,IP)=-((3.141593-RAD)/0.7853981)*XS
  477 IF(W(LOM,IP).GT.DBMAX) W(LOM,IP)=DBMAX
      IF(W(LOM,IP).LT.DBMIN) W(LOM,IP)=DBMIN
  479 Y(IP)=(ALOG10(OMEGA/YLOGMN)*LY/NUMDEC)*YS
  500 IF(INCRMT.LT.900) GO TO 518
C**************************GRAPHICAL CURVE PLOTTING*********************
      IF(IP-1)501,505,507
  501 IF(JCURVE.GT.0) GO TO 503
      WRITE(6,502) LOM
  502 FORMAT(10X,'NO GRAPH POINTS WERE FOUND FOR CURVE NUMBER ',I2)
      IF(NPARAM.NE.7) WRITE(6,207) ZSIGN
      GO TO 518
  503 WRITE(6, 504)LOM
  504 FORMAT(10X,'NO FURTHER POINTS WERE FOUND FOR CURVE NO.',I3)
      IF(NPARAM.NE.7) WRITE(6,207) ZSIGN
      GO TO 518
  505 WRITE(6,506)
  506 FORMAT(10X,'ONLY ONE POINT WAS FOUND, AND WILL NOT BE PLOTTED',/)
      GO TO 516
  507 J=LOM+50
      IF((ZSIGN.GT.0.0).AND.(JCURVE.GT.0))J=50
      JCURVE=1
      IF(IGRAPH.LE.-2) GO TO 516
      IF((NPARAM.EQ.7).AND.(IPAR7.LT.NPAR7))GO TO 518
      WRITE(6,511)LOM
  511 FORMAT(/,10X,'THE PREVIOUS POINTS WILL BE PLOTTED AS CURVE ',I2,/)
      IF(NPARAM-7)514,512,514
  512 WRITE(6,513)YMAGPK,OMEGPK
  513 FORMAT(/,10X,'THE MAXIMUM VALUE OF MAGNITUDE IS',F10.4,' LOCATED A
     &T OMEGA EQUAL TO',F10.4,/)
      J=50
  514 CALL DRAW(IP,X,Y,MOD,0,LA(J),ITITLE,XS,YS,IX,IY,2,2,LX,LY,1,LAST)
      MOD=2
  516 IP=0
  518 CONTINUE
      IF(NPARAM.EQ.7) GO TO 520
  519 CONTINUE
  520 CONTINUE
      IF((IPAR7.GE.NPAR7).OR.(NPARAM.NE.7)) GO TO 529
C*******GAMMA & PARAM-7 SUPERPOSITION ; SEE INPUT DATA SYMBOL NGAMMA****
  517 IF((NGAMMA.LE.0).OR.(IGAMMA.GT.NGAMMA)) GAMMA=0.0
      IF(IPAR7.GT.1)GO TO 523
      DO 521 I=1,LOE
      OLDHA(I)=HA(I)
      OLDHAT(I)=HAT(I)
      OLDHBT(I)=HBT(I)
  521 OLDHCT(I)=HCT(I)
      DO 522 I=1,MOE
      OLDHD (I)=HD (I)
      OLDHDT(I)=HDT(I)
      OLDHET(I)=HET(I)
  522 OLDHFT(I)=HFT(I)
  523 IPAR7=IPAR7+1
      IF(NGAMMA.GT.0) GO TO 526
      READ(5,5) (HA(I),I=1,LOE)
      READ(5,5) (HAT(I), I=1,LOE)
      READ(5,5) (HBT(I), I=1,LOE)
      READ(5,5) (HCT(I), I=1,LOE)
      READ(5,5) (HD (I), I=1,MOE)
      READ(5,5) (HDT(I), I=1,MOE)
      READ(5,5) (HET(I), I=1,MOE)
      READ(5,5) (HFT(I), I=1,MOE)
      IF(IPAR7.LT.NPAR7) GO TO 200
      DO 525 LOM=1,NLIMIT
      IP=IC(LOM)
      DO 524 I=1,IP
      X(I)=-U(LOM,I)
  524 Y(I)=V(LOM,I)
      J=LOM+1
  525 CALL DRAW(IP,X,Y,MOD,0,LA(J),ITITLE,XS,YS,IX,IY,2,2,LX,LY,1,LAST)
  526 DO 527 I=1,LOE
      HA (I)=OLDHA (I)+GAMMA*GAMHA (I)
      HAT(I)=OLDHAT(I)+GAMMA*GAMHAT(I)
      HBT(I)=OLDHBT(I)+GAMMA*GAMHBT(I)
  527 HCT(I)=OLDHCT(I)+GAMMA*GAMHCT(I)
      DO 528 I=1,MOE
      HD (I)=OLDHD (I)+GAMMA*GAMHD (I)
      HDT(I)=OLDHDT(I)+GAMMA*GAMHDT(I)
      HET(I)=OLDHET(I)+GAMMA*GAMHET(I)
  528 HFT(I)=OLDHFT(I)+GAMMA*GAMHFT(I)
      IF(IGAMMA.LE.NGAMMA) GO TO 26
  529 IF((NPARAM.NE.7).OR.(IGRAPH.LE.-2)) GO TO 999
C**************************PARAM 7 PHASE CURVES*************************
      IPAR7=2
      IF(IPHASE)537,532,999
  532 DO 536 LOM=1,NLIMIT
      IP=IC(LOM)
      DO 533 I=1,IP
      X(I)=W(LOM,I)
  533 Y(I)=V(LOM,I)
  536 CALL DRAW(IP,X,Y,MOD,0,LA(50),JTITLE,XS,1.,0,IY,2,2,LX,LY,1,LAST)
      IPAR7=1
  537 IF((IPOLAR).LE.(0)) GO TO 999
C**************************PARAM 7 POLAR PLOT CURVES********************
      MOD=1
      DO 542 I=1,8
      RADIUS=I/2.0
      DO 539 J=1,360
      RADIAN=6.28318/360*J
      X(J)=RADIUS*COS(RADIAN)
  539 Y(J)=RADIUS*SIN(RADIAN)
      CALL DRAW(J,X,Y,MOD,0,LA(1),KTITLE,1.,1.,4,4,2,2,8,8,0,LAST)
  542 MOD=2
      DO 543 J=10,180,10
      X(1)=X(J)
      X(2)=-X(1)
      Y(1)=Y(J)
      Y(2)=-Y(1)
  543 CALL DRAW(2,X,Y,2,0,LA(1),KTITLE,1.,1.,4,4,2,2,8,8,0,LAST)
      DO 545 LOM=1,NLIMIT
      IP=IC(LOM)
      DO 544 J=1,IP
      X(J)=S(LOM,J)
  544 Y(J)=T(LOM,J)
      L=LOM+1
  545 CALL DRAW(IP,X,Y,2,0,LA(L),KTITLE,1.,1.,4,4,2,2,8,8,0,LAST)
  999 IF((MOD).NE.(2)) GO TO 1000
C***********TERMINATING GRAPH LINE FOR EACH PLOT*************************
      X(1) = 0.0
      Y(1) = 0.0
      X(2) = (LX-IY)*XS
      Y(2) = 0.0
      CALL DRAW (2,X,Y,3,0,LA(50),ITITLE,1.0,1.0,0,0,2,2,LX,LY,1,LAST)
      MOD=1
      IF((IPAR7).EQ.(1)) GO TO 1000
  530 DO 531 I=1,12
  531 ITITLE(I)=JTITLE(I)
      GO TO 55
 1000 CONTINUE
      STOP
      END
```

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13. ABSTRACT

The use of parameter plane curves of output voltage magnitude versus one of the parameters as a means of obtaining the frequency response of nonlinear networks was investigated for networks containing one nonlinear element, which was a function of the magnitude of the voltage across it. The results obtained were checked by digital simulation and it may be concluded that the method is reliable. The method was also presented as a way of obtaining information for the reshaping of network frequency response by introduction of the proper nonlinear elements.

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